The BioTown, USA
Sourcebook of
Biomass Energy

Indiana State Department of Agriculture
&
Reynolds, Indiana

Prepared by

Mark Jenner, PhD.
biomassrules@markjenner.com

Table of Contents

BioTown Sourcebook Executive Summary

BioTown, USA is Indiana Governor, Mitch Daniel's, bold approach to develop local renewable energy production, create a cleaner environment, find new solutions to municipal/animal waste issues, and develop new markets for Indiana products – all at the same time. BioTown, USA is quite simply the conversion of Reynolds, Indiana from a reliance on fossil fuels to biomass-based fuels. With the implementation of BioTown, USA, a template will be set that simultaneously promotes Indiana energy security, rural development, profitable agriculture and a green, thriving natural resource environment.

BioTown, USA is profoundly thermodynamically and technologically viable. Reynolds, Indiana used 227,710 million BTUs (MMBTU) in 2005. Without including existing bioenergy projects like the 3.2 MW generating capacity at the Liberty Landfill, White County annually produces over 16,881,613 MMBTU in undeveloped biomass energy resources. That is 74 times more energy than Reynolds consumed in 2005.

BioTown, USA Annual Energy Consumption

To set energy use levels as an energy replacement target, estimates for Reynolds' energy use were made based on 2005 levels of liquid fuel (384,000 gallons of unleaded gasoline), total residential and commercial electricity use (8,046,934 kilowatt-hours), and combined residential and commercial natural gas (147,721,090 cubic feet, Table ES.1).

Table ES.1 BioTown, USA 2005 Energy Estimates

			Million BTU
Reynolds BP regular gasoline	384,000	Gallons	48,000
Reynolds residential electricity	2,881,135	kW-hr	10,000
Reynolds commercial electricity	5,165,799	kW-hr	18,000
Reynolds residential natural gas	29,561,910	Cubic feet	30,360
Reynolds commercial natural gas	118,159,180	Cubic feet	121,349
Total			**227,710**

Energy use was assigned a BTU value based on established measurements. The total annual energy use of Reynolds, Indiana is estimated at 227,710 million BTUs (MM BTU).

Inventory of Available Biomass Feedstocks

Selection of a biomass energy conversion technology is dependent on locally available biomass materials. A broad inventory was made on available materials/feedstocks in Reynolds and the surrounding area for use as fuels in biomass conversion technologies. Materials that currently exist are: corn grain, corn stover, soybeans, swine manure, Reynolds' sewage, Monticello's sewage, White County septic tank clean-out material, brown grease, yellow grease and Municipal Solid Waste (MSW, Table ES.2). In addition, estimates of other biomass energy crops that could be introduced into White County were made: canola, switchgrass, miscanthus, and hybrid poplar.

Table ES.2 Reynolds and White County Gross Energy Production Estimates

	Energy	Supply	Total Energy
Corn - Grain	8,100 BTU/lb	130,000 acres, county	8,000,000 MMBTU
Corn - Stover	7,800 BTU/lb	130,000 acres, county	7,700,000 MMBTU
Soybeans	15,400 BTU/lb	117,700 acres, county	870,000 MMBTU
Swine Manure	650 BTU/cf	150,000 hog capacity	150,000 MMBTU
Reynolds Sewage	8,217 BTU/lb	26,000 lbs, Reynolds	214 MMBTU
Monticello Sewage	8,217 BTU/lb	326,000 lbs, Monticello	2,679 MMBTU
Septage	8,217 BTU/lb	910,000 gallons, county	950 MMBTU
Brown Grease	15,400 BTU/lb	390,000 gallons, county	770 MMBTU
Yellow Grease	15,400 BTU/lb	2,219,000 lbs, 354 restaurants	34,000 MMBTU
MSW+	4,830 BTU/lb	12,700 tons, county	123,000 MMBTU
Total			**16,881,613 MMBTU**

+ MSW in White County is already powering 3.2 MW of electrical power generation. This is not part of these estimates.

By comparing total *gross* energy produced in Reynolds and the surrounding area with energy-use estimates of Table ES.1, Reynolds would consume roughly 1.3 percent of energy produced in the surrounding area[1]. Conversely, 74 times more energy is produced in Reynolds and the surrounding area, than is consumed in Reynolds on an annual basis. These energy estimates are based on the available feedstocks on current, 'as-is' basis. Based on these raw feedstocks, BioTown, USA has much more energy available than the community currently uses each year.

The implementation of BioTown, USA by local leaders of Reynolds and White County, local farmers and residents, the BioTown Task Force, the Indiana Office of Energy and Defense

[1] '*Gross*' energy is tabulated here because the focus is on energy replacement of Reynolds. No attempt is made to minimize the energy required to produce crops, livestock and human waste materials in the area. Moving the assessment to a '***net***' energy production inventory will be the focus of later analyses.

Development and the Indiana State Department of Agriculture, will determine the most technically and economically efficient methods required to convert available feedstocks into real energy replacement.

Biomass Energy Conversion Technology – or Tools in the BioTown Toolbox.

The technologies listed in Table ES.3 form the list of basic technologies reviewed in the BioTown, USA Sourcebook. Each technological process was reviewed and, for most technologies, vendor contacts were listed as a place to start for gathering more information.

Table ES.3 Current Scale of Biomass Conversion Technology by Economic and Technical Efficiency

Biomass Conversion Technologies	Pilot-scale	Commercial-scale
Combustion		
Small-scale Furnaces (heat)		xxx
Large-scale Biomass Furnaces (heat)		xxx
Large-scale Biomass Power Plants (heat & electricity)		xxx
Co-generation Power Plants		xxx
Gasification	xxx	
Fast Pyrolysis Bio-Oils	xxx	
Anaerobic Digesters		xxx
Ethanol Fermentation		
Corn to Ethanol		xxx
Fiber to Ethanol (cellulosic)	xxx	
Transesterification of Vegetable Oil (Biodiesel)		
Virgin Vegetable Oil as a Feedstock		xxx
Used Vegetable Oil and Animal Fat as a Feedstock	xxx	

This BioTown, USA Sourcebook serves as a starting place for the implementation of BioTown, USA. It is intended to be a dynamic document that will grow and improve with use.

1 Biomass Energy Sourcebook Basics

1.1 Transforming Reynolds, Indiana into BioTown, USA

On September 13, 2005, Indiana Governor Mitch Daniels unveiled the BioTown, USA concept[2]. BioTown is Indiana's inaugural effort toward creating communities where all energy needs are met through use of biorenewable resources. Reynolds, the first BioTown, USA, will showcase the feasibility of existing and future technologies in utilizing agricultural products and their by-products as fuel, electricity and heating sources.

"BioTown, USA is an aggressive plan to create a model for rural communities throughout our state and country," said Governor Daniels. "We are taking challenges and turning them into opportunities by developing homegrown, local energy production to become independent from foreign sources; creating a cleaner environment; finding new solutions to animal waste management issues; and developing new markets for Indiana agricultural products and by-products."

"Our goal is to make Indiana a leader in the future of agriculture, and to do that, we must be progressive in advancing new uses for our products and finding more environmentally-friendly ways to dispose of our by-products," said Indiana Agriculture Director Andy Miller. "In our efforts to grow our livestock industry, we will not ignore our responsibility to the environment. Therefore, it is our goal to recycle manure and other waste products into useful inputs, and energy production is a good example."

BioTown, USA is a project of the Indiana State Department of Agriculture (ISDA). In mid-May ISDA rolled out its strategic plan, Possibilities Unbound: The Plan for 2025, Indiana Agriculture's

[2] Adapted from the Indiana State Department of Agriculture's 9/13/05 press release, "*Governor Daniels unveils first BioTown, USA*"

Strategic Plan. This document describes the Department's focus and guiding principles for the next several years. The plan contains seven strategies to grow Indiana agriculture, one of which is bioenergy. The action plan for this strategy calls for the development of a pilot community that meets all of its energy needs through biorenewable resources.

1.2 Biomass Energy Basics

Biomass is recently generated plant material. The time component separates biomass from the prehistoric plant-derived products like coal and crude oil. Biomass includes virgin plant products like grains, grass and wood, and processed plant material like paper, manure, and other plant-based wastes and residuals.

1.2.1 Stored Solar Energy. One of the fundamental relationships in nature is the photosynthesis of carbon dioxide and water into carbohydrates and oxygen through sunlight absorbed through green plants (Equation 1.1). Quite simply, green plants store solar energy biochemically as sugars, starches, lipids and fibers.

Equation 1.1 Photosynthesis

$$6CO_2 + 6H_2O + \text{ sunlight } \Rightarrow C_6H_{12}O_6 + 6O_2$$

Agriculture has always understood this process. All the value of our food and fiber commodities (corn, beans, wheat, cotton, timber, etc.) is based on photosynthesis. Shifting the market discussion from the hidden energy value of traditional commodities to biomass products is as simple as shifting from corn, beans, manure and timber to sugars, starches, lipids and fibers.

The stored solar energy in green plants is accessible through the converse of photosynthesis, or respiration (Equation 1.2)[3].

Equation 1.2 Respiration (glucose)

$$C_6H_{12}O_6 + 6O_2 \Rightarrow 6CO_2 + 6H_2O + 686\,Kcal/mole\ \ (heat)$$

1.2.2 Thermodynamics of Farming. Tracking the energy of production agriculture is a relatively new concept. U.S. agriculture has evolved on the basis of marketing commodities, not on the

[3] Darnell, James, Harvey Lodish and David Baltimore, Molecular Cell Biology 2nd Ed., Scientific American Books. New York. 1990 p. 37.

efficiency of energy utilization. It takes more energy to raise a pound of meat than a pound of grain. While the pound of meat tastes better than the 3 - 5 pounds of grain, producing the meat is not very thermodynamically efficient. The good news is the traditional way of designing and managing production systems is evolving.

Energy is fixed in the universe. It can not be created or destroyed (First Law of Thermodynamics). All energy moves toward greater disorder (Second Law of Thermodynamics). Energy can only be conserved. It can not be recycled like nutrients. Solar energy strikes the planet and bounces off. This energy is captured and chemically stored in plants until it is used or lost.

There is a great deal of residual energy that passes through each farming enterprise unused. By looking at the energy balance of farming systems, the system efficiency can be increased. This can be extended beyond production systems to all food waste, trash and all organic residuals. Just like manure is *'unused'* corn and soybeans, all organic residuals contain stored, underutilized energy. Developing biomass energy technologies increase the utilization and conservation of energy by managing the unused energy in plant material.

1.2.3 Is Biomass Energy Based on Carbohydrates or Hydrocarbons? Both, sort of. Biomass energy is based on carbohydrates, but the existing energy production, distribution and use, are based on the chemistry of fossil-fuels, or hydrocarbons. Much of the biomass energy work that has been done focuses on conversion of biomass carbohydrates into the current energy units of hydrocarbons.

Sugars, like glucose, are basic energy units of biomass. Glucose is a six carbon sugar ($C_6H_{12}O_6$). The five carbon sugar, pentose, is another important basic energy unit. Starches and fibers (cellulose) are larger combinations of the five and six carbon sugars. Protein, fat and lignin contain different ratios of C, H and O molecules, but are not as easily transformed into basic sugars.

Hydrocarbons, a basic unit of traditional energy, by definition contain carbon and hydrogen in various ratios. Hydrocarbons do not require the presence of an oxygen molecule. Important classes or groups of hydrocarbons include: *alkane*, alkene, alkyne, aromatic hydrocarbon, *alcohol*, ether, aldehyde, ketone, carboxylic acid, *ester*, amine, and amide[4]. While these terms may be intimidating, common biofuels like ethanol is of the hydrocarbon class *alcohol*, biodiesel is of the hydrocarbon class *ester,* and methane gas is of the hydrocarbon class *alkane*.

A reasonable first step for biomass energy has been to convert complex carbohydrates into simple hydrocarbons. The more complex the feedstock carbohydrate, the more difficult the conversion to hydrocarbon fuels. Some processes formulate simple sugars, but also create associated products that confound the use of the sugars. Feedstocks with high levels of lignin present other issues as the presence of lignin interferes with accessing the sugars.

The rigorous application of physics, biology and chemistry to plant materials is identifying new pathways of converting complex plant materials into simple hydrocarbon fuels. Subsequent advances in research and application of the initial alcohol stills and methane digesters of twenty years ago makes BioTown, USA an achievable reality, today.

Biomass energy systems are not composed of a single process. To conserve the stored solar energy, multiple processes are woven into a complete system. It is likely that some of the bioprocessing technologies will not produce energy, but some other useful outputs like construction materials, compost, or industrial chemicals. A complete system of processing technologies a biomass energy system is conceptually similar to an oil refinery. The Biorefinery Concept is very appropriate for the path that lies ahead for BioTown[5]. For BioTown, USA, the conversion of carbohydrates to power will look like Figure 1.1.

[4] Brown, Robert, Biorenewable Resources: Engineering New Products from Agriculture. Iowa State Press. Ames, IA 2003. p. 28.

[5] Paster, Mark, Joan L. Pellegrino, and Tracy M. Carol, *"Industrial BioProducts: Today and Tomorrow,"* for U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Office of the Biomass Program, Washington, D.C. July 2003 http://www.bioproducts-bioenergy.gov/pdfs/BioProductsOpportunitiesReportFinal.pdf

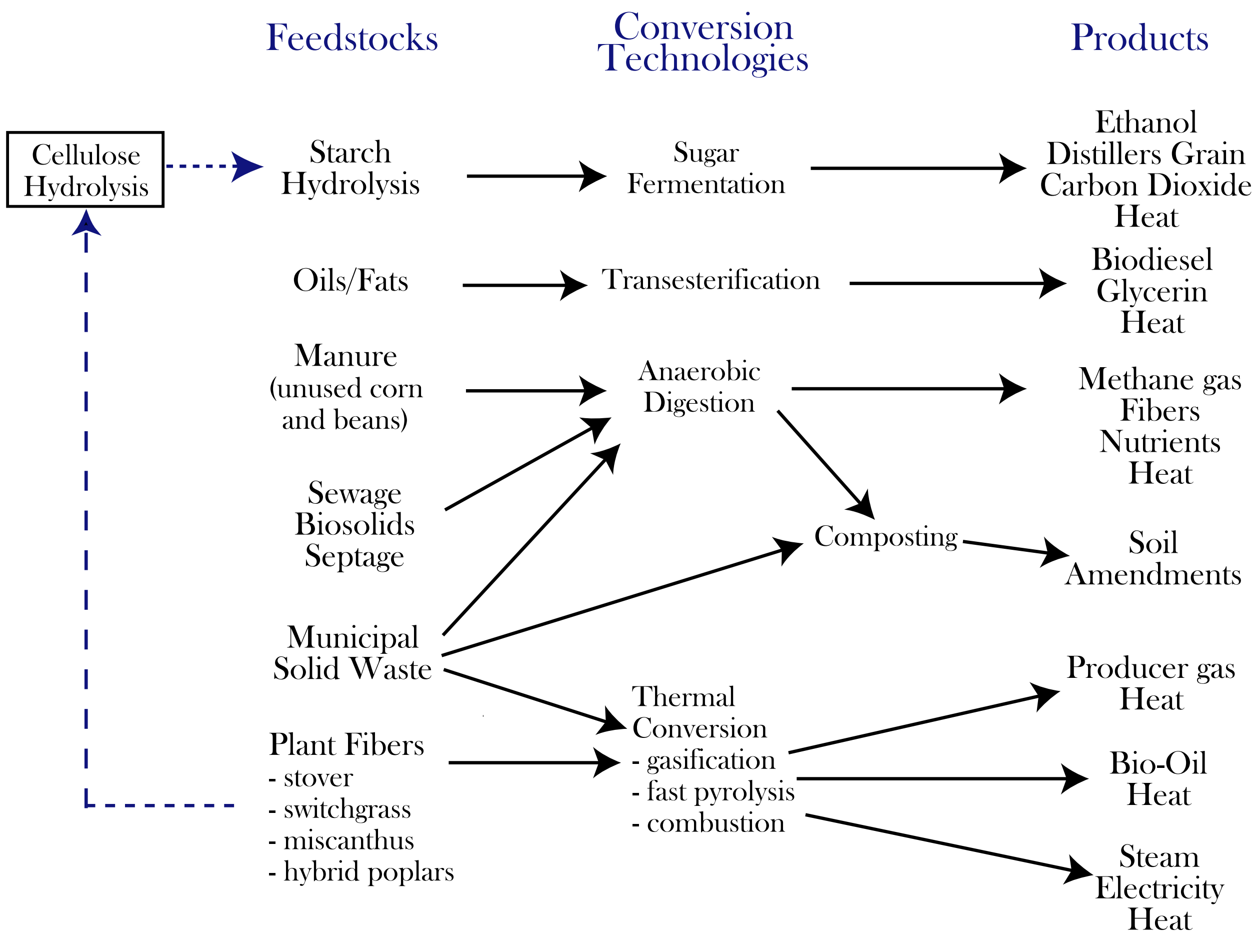

Figure 1.1 The Biorefinery Concept Applied to BioTown, USA

1.3 Scope of Sourcebook

This BioTown, USA Biomass Energy Sourcebook is intended to be a dynamic reference. This work includes a discussion of energy use (liquid fuels, natural gas and electricity) of Reynolds, Indiana. It describes all identified, available biomass feedstocks in Reynolds and White County, Indiana. This Sourcebook also highlights the latest cutting edge technologies that are either at the commercialization stage or nearing the commercialization stage.

This BioTown, USA Sourcebook has been compiled to provide reference information for use by the BioTown Task Force, the leadership of Reynolds, White County, and the Indiana State Department of Agriculture to assist in making the most informed decisions concerning BioTown. New materials will be added as they become available.

2 Energy Use and Distribution Systems of BioTown

Current use of transportation fuels, electricity and natural gas equivalents sets the target for biomass fuel conversion in BioTown, USA. The estimate for those categories are based on energy use of the energy suppliers in Reynolds during 2005.

One aspect of BioTown, USA that makes it so vital to the future of Indiana residents is the rising cost of energy. While the price of electricity has risen 8-9 percent over the last five years, the price of crude oil, unleaded gasoline, coal and the price of heating oil have nearly doubled in the last five years (100 percent increase). The price of crude oil topped $70 per barrel in 2005, while up to that time the price of $40 per barrel had set an 'upper limit' in all biomass energy economic analyses. With the increasing energy price shocks of 2005 the feasibility of biomass energy snapped into focus.

2.1 Transportation Fuels

The liquid transportation fuels portion is Phase I of BioTown. The annual sales of fuel at the Reynolds BP station, at Junction of Hwy. 24 & Hwy. 421, serve as the basis of the BioTown, USA liquid fuel goal. The volume of fuel sold in 2005 is estimated at 32,000 gallons per month[6]. Annually the volume of liquid fuel sold in Reynolds is 384,000 gallons. Using the energy content of 125,000 BTU/gallon, the total energy use of Reynolds is 48,000 Million British Thermal Units (MMBTU) per year.

As mentioned above, 2005 prices for gasoline and crude oil have been record-breaking. Figure 2.1 shows the last five years of spot prices for unleaded gasoline (NY Harbor)[7]. These unleaded gasoline prices are lower than the prices paid locally because they do not include transportation and taxes. Similarly, the last five years of crude oil spot prices (Cushing, OK) show a direct relationship to the unleaded gasoline prices (Figure 2.2).

[6] John Harris, Reynolds BP was very supportive in supplying local 2005 gasoline sales volume estimates.

[7] James L. Williams, WTRG Economics, was very helpful and instructive on energy prices. WTRG Economics supplies all energy prices series, except those supplied by the EIA. WTRG Economics, PO Box 250. London, AR 72847, 479-293-4081 www.wtrg.com.

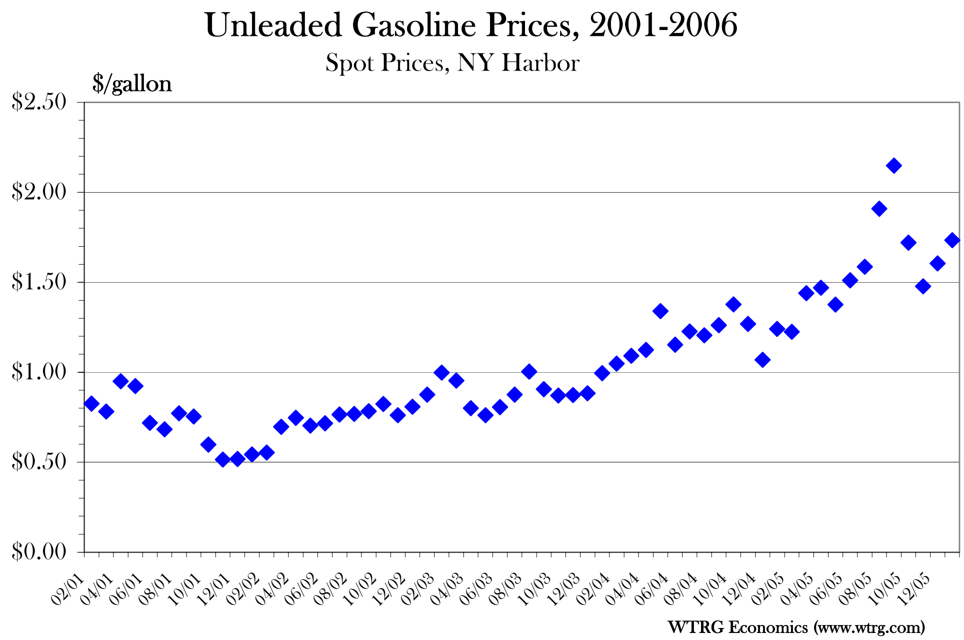

Figure 2.1 Unleaded Gasoline Spot Prices, NY Harbor (WTRG Economics)

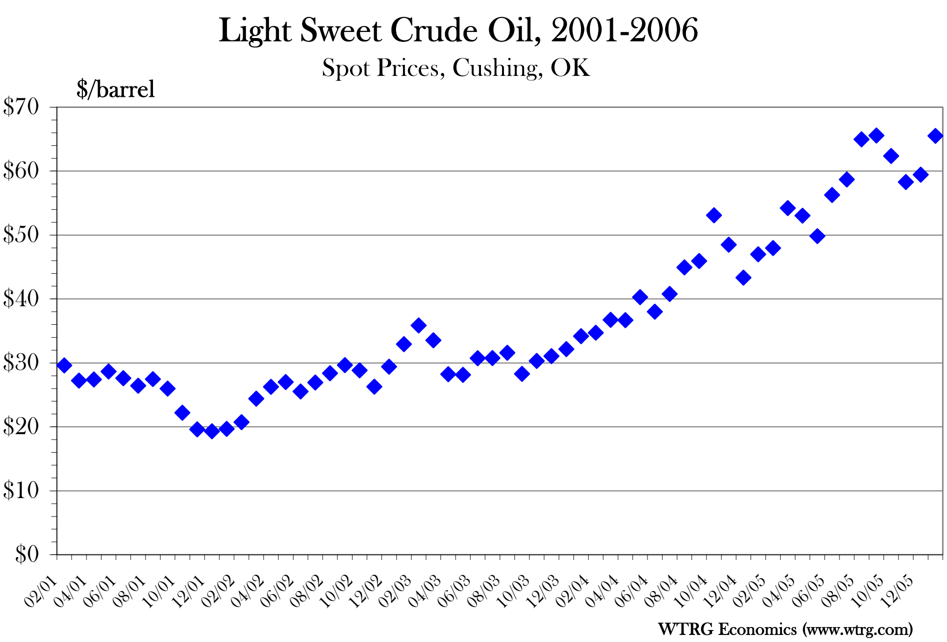

Figure 2.2 Light Sweet Crude Oil Spot Prices, Cushing, OK (WTRG Economics)

2.2 Electricity

Electricity is supplied in Reynolds by Northern Indiana Public Service Company (NIPSCO). NIPSCO has supplied the residential and commercial annual electricity use for Reynolds (Table

2.1)[8]. Reynolds, Indiana used 8,046,934 kilowatt-hours (KWH) in 2005, which is equivalent to 28,000 MMBTU annually.

Table 2.1 Reynolds 2005 Residential and Commercial Electrical Use (KW Hours)

	Number	Total KWH	Average KWH
Residential	358	2,881,135.0	8,047.9
Commercial	49	5,165,799.0	105,424.5
Total	407	8,046,934.0	

Electricity prices have increased at the slowest rate over the last five years (Figure 2.3).[9] Peak demand for electricity occurs during the summer months. Prices are the lowest during the winter months. The Energy Information Administration (EIA) data series below went through October of 2005, so it is two months short of five years.

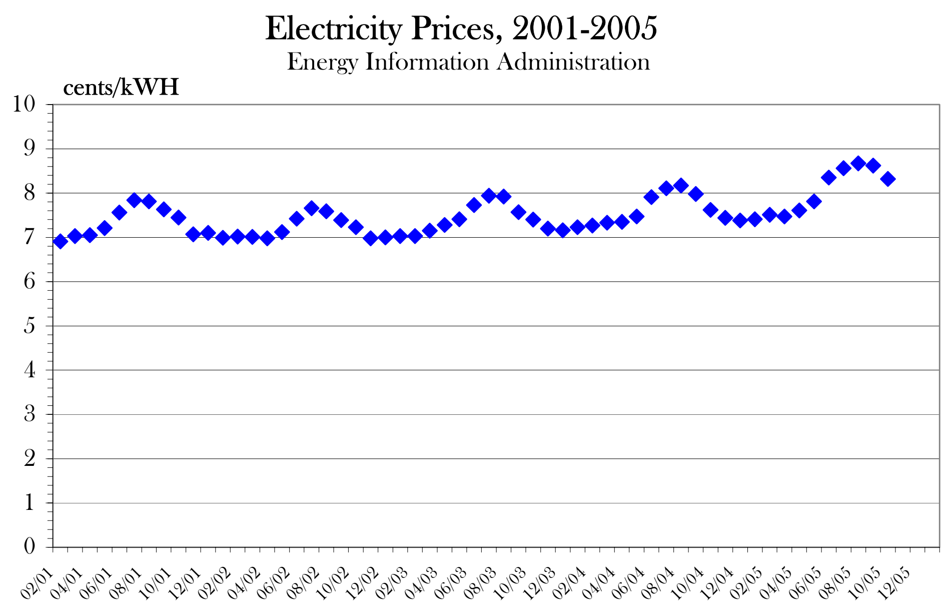

Figure 2.3 Electricity Prices, 1/01 - 10/05 (EIA)

Coal produces most of the electricity produced in the U.S. As a basis for economic pressure on electricity demand, the last four years of coal futures are included (2002 – 2005, Figure 2.4)[10].

[8] Jim Fitzer, NIPSCO, was very supportive in supplying estimate of 2005 electricity use for Reynolds. Total number of users is based on those NIPSCO customers that reside in the 47980 (Reynolds) zip code.

[9] Energy Information Administration, Monthly Energy Review (MER) January 2006, Table 9.9, Average Retail Prices of Electricity. http://www.eia.doe.gov/emeu/mer/prices.html

[10] Energy Information Administration, U.S. Department of Energy http://www.eia.doe.gov/cneaf/coal/page/nymex/nymex_chart.pdf

While electricity prices have increased less than 10 percent over the last four years, coal prices have nearly doubled over a similar time period. In Chapter Five, Table 5.1 compares shelled corn to fossil fuels on the basis of BTU content. Here, even $60 per ton for coal is a great value compared to an equivalent BTU level of $111 for shelled corn (3,360 lbs corn at $1.85/bushel).

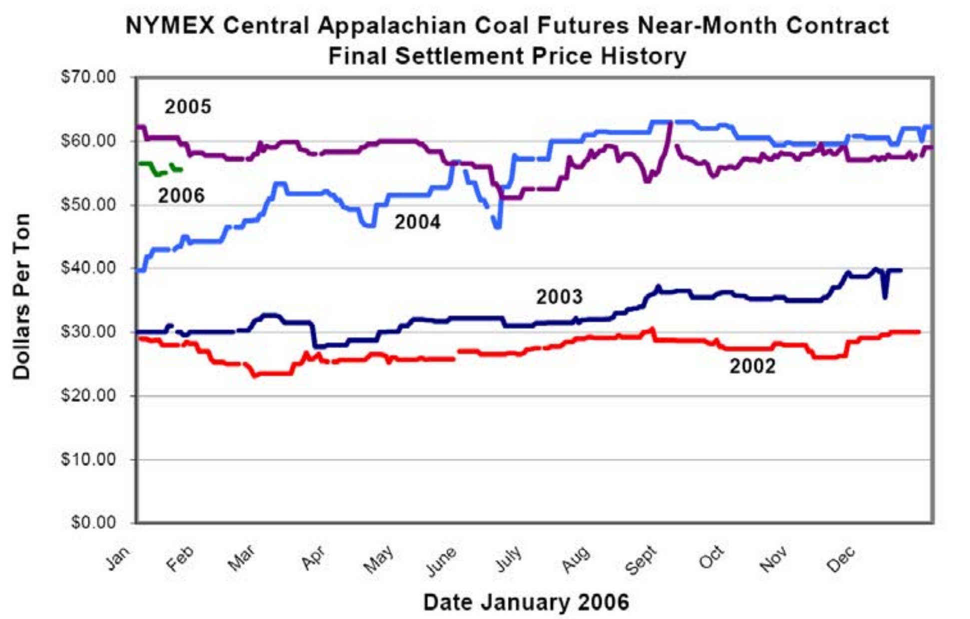

Figure 2.4 Historical Coal Prices (Energy Information Administration - EIA)

While the NIPSCO service area in Reynolds serves as an excellent standard for BioTown to meet, the biomass-derived replacement electricity will ultimately be a combination of energy generated in the NIPSCO service area and energy generated in the White County REMC service area.

2.3 Natural Gas

Natural gas is also supplied in Reynolds by Northern Indiana Public Service Company (NIPSCO). NIPSCO has supplied the residential and commercial annual natural gas use for Reynolds (Table 2.2)[11]. While the NIPSCO clients are generally both electricity and natural gas customers, the actual number of clients between the two differs a bit.

[11] Jim Fitzer, NIPSCO, was very supportive in supplying estimate of 2005 natural gas use for Reynolds. Total number of users is based on those NIPSCO customers that reside in the 47980 (Reynolds) zip code.

Table 2.2 2005 Reynolds Natural Gas Residential and Commercial Use (CF)

	Number	Total CF	Average CF
Residential	323	29,561,910	91,522.9
Commercial	17	118,159,180	6,950,540.0
Total	340	147,721,090	

In 2005, Reynolds, Indiana consumed 147,721,090 cubic feet (CF), or an annual use of 151,710 MMBTU.

As with liquid fuels, natural gas prices have hit record highs in 2005. The last five years 2001 – 2006, natural gas spot prices from the Henry Hub were included as an indicator of pressure on natural gas use (Figure 2.5)[12]. Even if the record high prices of 2005 are considered to be caused by the unusual Hurricane Katrina event, natural gas prices have more than doubled since the winter of 2001.

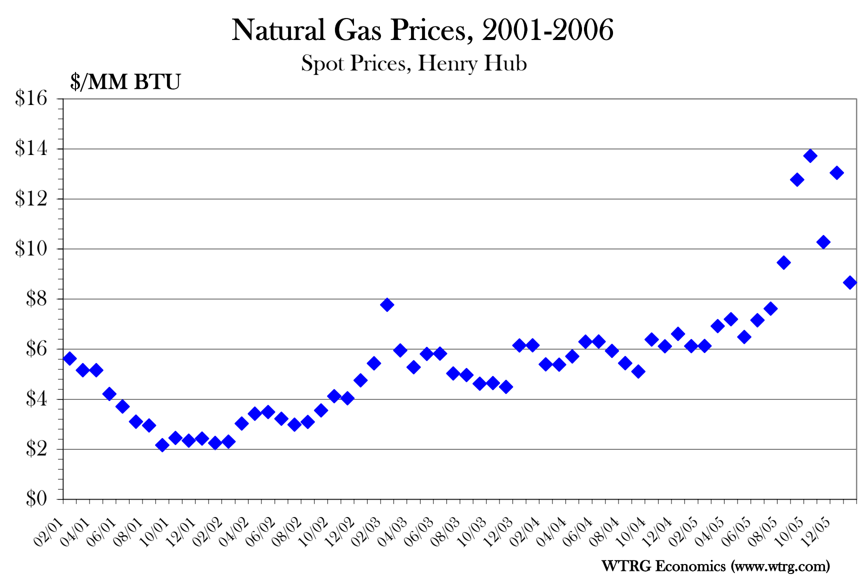

Figure 2.5 2005 Natural Gas Spot Prices from the Henry Hub (WTRG Economics)

Although BioTown, USA energy use focuses only on natural gas for heat energy, it is useful to include a brief discussion on heating oil prices. In many ways, biodiesel and other liquid fuels produced from biomass energy conversion (like the bio-oil of fast pyrolysis), are direct replacements for fossil fuel-derived heating oil. The price of heating oil has also more than doubled in the last five years (Figure 2.6)[13].

[12] Natural gas prices provided by WTRG Economics, www.wtrg.com.
[13] The heating oil prices provided by WTRG Economics, www.wtrg.com.

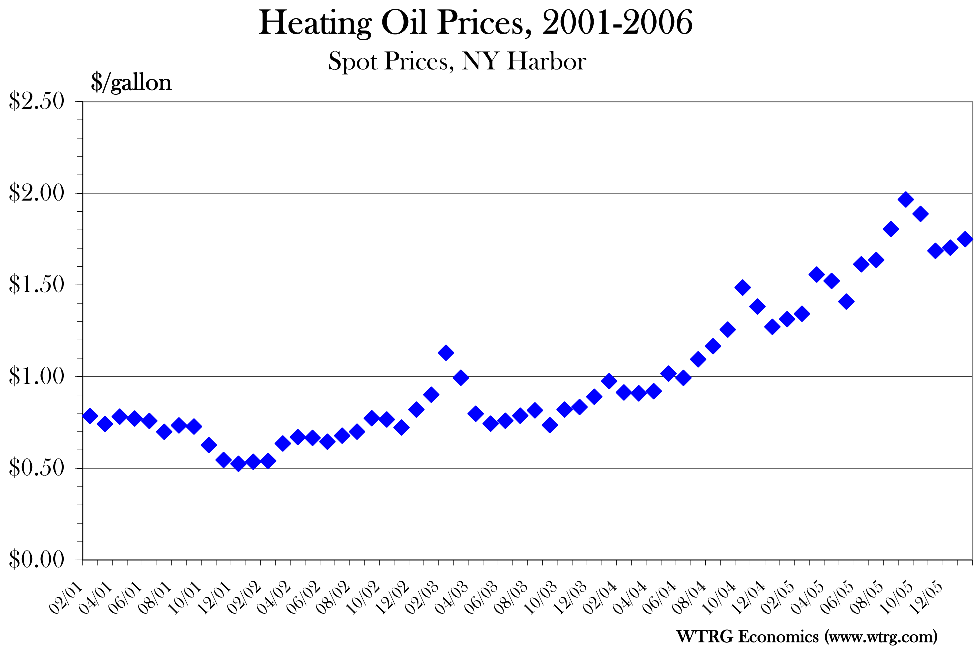

Figure 2.6 Heating Oil Prices, NY Harbor, 2001 - 2006 (WTRG Economics)

2.4 Annual Energy Use of BioTown, USA

The annual energy consumption of 227,710 MMBTU of fossil-derived fuel serves as a representative target for BioTown, USA to replace with biomass-derived fuels (Table 2.3).

Table 2.3 Annual Energy Use of Reynolds, IN (2005)

			Million BTU
Reynolds BP regular gasoline	384,000	Gallons	48,000
Reynolds residential electricity	2,881,135	kW-hr	10,000
Reynolds commercial electricity	5,165,799	kW-hr	18,000
Reynolds residential natural gas	29,561,910	Cubic feet	30,360
Reynolds commercial natural gas	118,159,180	Cubic feet	121,349
Total			227,710

The bottom line is that as the cost of fossil fuel-derived energy continues to roughly double every five years, the value of biomass energy makes excellent economic sense. Agricultural commodity prices have remained competitively low for decades. Historically, if the supply of corn, beans, or even hogs is below demand, more are grown the next year – keeping commodity prices low.

3 Biomass Feedstocks

Biomass feedstocks can be any recent plant-based carbon material. This chapter discusses the supply of raw materials and inputs into biomass energy that can be found or produced in Reynolds and White County, Indiana. Feedstocks covered include shelled corn, corn stover, soybeans, canola, dedicated energy crops, manure, sewage, used vegetable oil & grease, and municipal solid waste (MSW).

3.1 Corn

The National Agricultural Statistics Service (NASS), USDA reports corn production in White County, Indiana had an average 5-year corn yield for of 158.3 bushels/acre (2000 – 2004)[14]. During the same 5-year period, corn acreage averaged 131,880 acres in White County. The average total annual production was 20,874,720 bushels of shelled corn. In the 2002 Census of Agriculture, White County produced the most bushels of shelled corn in Indiana[15].

Corn is a bright star in the bioenergy future. It has bioenergy uses in ethanol and Dried Distillers Grains and Solubles (DDGS). The shelled corn functions as a natural fuel pellet for use in corn burning stoves and furnaces. The corn stover also contains biomass energy and shows promise as a biomass feedstock in energy production.

Shelled Corn	
8,100	BTU/pound[16]
130,000	White Co. acres
160	bu/acre
20.8	Million bushels
72.6	MMBTU/acre
8,000,000	MMBTU[17]

3.1.1 Grain For most of the last 30 years farmers in White County have harvested nearly 130,000 acres of corn. While corn acreage has remained fairly constant, corn yields have continued to increase (Figure 3.1). Thirty years ago the average annual corn yield in White County was about 100 bushels/acre. Corn yields are forecasted to continue increasing with biotechnology and precision agriculture.

[14] USDA-NASS. Quick Stats. Corn and soybean history. http://www.nass.usda.gov/Statistics_by_State/Indiana/index.asp
[15] USDA 2002 Census of Agriculture, White County, Indiana Corn Production. http://151.121.3.33:8080/Census/Create_Census_US_CNTY.jsp
[16] AURI Fuels Initiative http://www.auri.org/research/fuels/pdfs/fuels.pdf
[17] MMBTU = Million British Thermal Units (BTU).

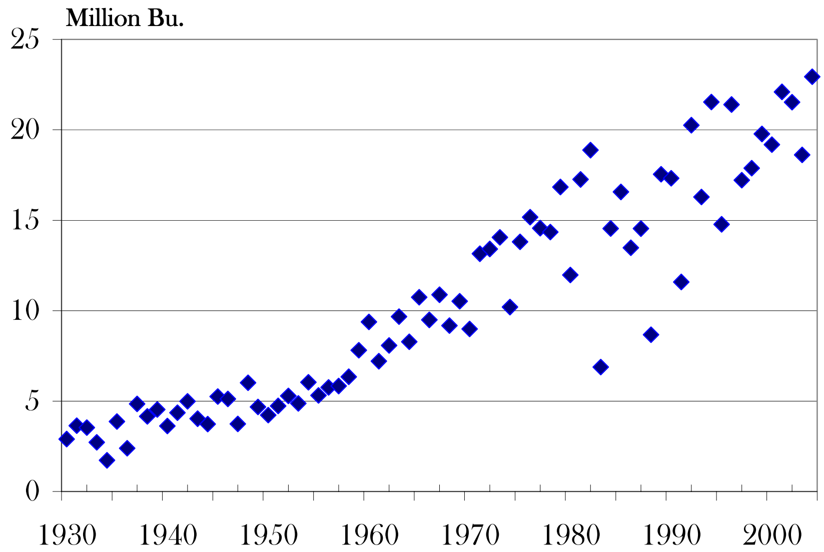

Figure 3.1 White County Corn Production 1930-2004

It can be seen in Table 3.1 that current 160 bu/acre yields for 130,000 acres produce about enough corn for a 50 million-gallon per year ethanol plant (20 million bushels of corn). The Higher Heating Values (HHV) represent a reference value for energy released through combustion. The measurements are based on relatively few samples and produce a wide range of variation in available tabled HHV values. The available tabled values serve as a starting point for comparison of biomass feedstocks.

Table 3.1 Higher Heating Value of White County Shelled Corn and Stover

Yield (bu/ac)	Acres	Standard Bu. @56 lb/bu	Bone Dry Bu. @47.32lb/bu	Dry tons Grain	Raw energy MMBTU	Dry tons Stover[18]	Raw energy MMBTU
150	130,000	19,500,000	923,000,000	462,000	7,484,400	462,000	7,207,200
160	**130,000**	**20,800,000**	**984,000,000**	**492,000**	**7,970,400**	**492,000**	**7,675,200**
170	130,000	22,100,000	1,046,000,000	523,000	8,472,600	523,000	8,158,800
180	130,000	23,400,000	1,107,000,000	554,000	8,974,800	554,000	8,642,400
190	130,000	24,700,000	1,169,000,000	585,000	9,477,000	585,000	9,126,000
200	130,000	26,000,000	1,230,000,000	615,000	9,963,000	615,000	9,594,000

On the basis of weight, without adjusting for the energy mass balance, about one third of a bushel of shelled corn yields the 2.7 gallons of ethanol. Another third of the bushel (17-18 lbs) produces of DDGS and the final third (16-17 lbs) is carbon dioxide (CO_2)[19].

[18] Stover was estimated on a weight ration of 1:1, shelled corn to stover. See text below.

3.1.2 Stover The corn stalks, leaves and cobs make up corn stover. While very little corn stover is currently used as a biomass energy source, corn stover has been bailed in large round bails for bedding and feed during drought years[21].

Corn Stover	
7,800	BTU/pound[20]
130,000	White Co. acres
3.78	tons/acre
491,400	tons
59.0	MMBTU/acre
7,700,000	MMBTU

Corn grain yields are measured and tracked continually, though few measurements are taken on the corn stover yield. In the Billion Ton study, USDA/DOE describe a ratio of 1:1 of grain to stover by dry weight[22]. To get the dry weight, the standard test-weight moisture of 15.5% must be removed. Removing the moisture reduces the weight of a bushel of Number 2, Yellow Corn from 56 lbs down to 47.32 pounds per bushel.

3.2 Soybeans

The National Agricultural Statistics Service (NASS), USDA reports that soybean production in White County, Indiana had an average 5-year bean yield of 47.0 bushels/acre (2000 – 2004)[24]. During the same 5-year period, soybean acreage averaged 117,700 acres in White County. The five year average production was 5.5 million bushels of soybeans. Soybean acreage in the County has fluctuated between 100,000 and 120,000 acres for more than 10 years. County soybean production has increased steadily (Figure 3.2).

Soybeans
117,700 acres
47 bu/acre
5.5 million bushels
63 gal biodiesel/acre
117,000 BTU/gal[23]
15,400 BTU/lb
870,000 MMBTU

The authors of USDA/DOE's 'Billion Ton' report indicate that bean stalks can be harvested for biomass just as corn stover. The soybean stalk biomass yield is much lower than corn, but varieties are being identified that would increase crop residue significantly without lowering the bean yield.

---

[19] Brown, Robert, Biorenewable Resources: Engineering New Products from Agriculture. Iowa State Press. Ames, IA 2003.

[20] Sources vary 4,000–8,000 BTU/lb. AURI Fuels Initiative http://www.auri.org/research/fuels/pdfs/fuels.pdf

[21] Adams, Richard S., Penn State professor of Dairy Science *"Corn Stover As Feed For Cattle."* Pennsylvania State University. http://www.cas.psu.edu/docs/biosecurity/EMERGENCY/corn2.html

[22] Perlack, Robert D., Lynn L. Wright, Anthony F. Turhollow, Robin L. Graham, Bryce J. Stokes and Donald C. Erbach. 2005. "*Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply.*" USDA and DOE. Oak Ridge National Laboratory. April 2005.

[23] Jim Wimberly. Unpublished biofuels conversion tables. 2005

[24] USDA-NASS. Quick Stats. Corn and soybean history. http://www.nass.usda.gov/Statistics_by_State/Indiana/index.asp

Soybeans are harvested and crushed into bean meal (80% by weight) and oil (18.5% by weight). The meal is generally 44% protein, has high economic value and is the protein-standard around the world. The soybean oil also has high value. One of the values of oil is the conversion into biodiesel and glycerin (90:10 ratio). Jim Wimberly estimates 7.4 million BTUs per acre for a 47 bushel/acre yield (White County 5-year average)[25]. On 117,700 acres of beans that is 871,000 million BTUs (MMBTU) in the County. This does not include the energy of the soybean meal.

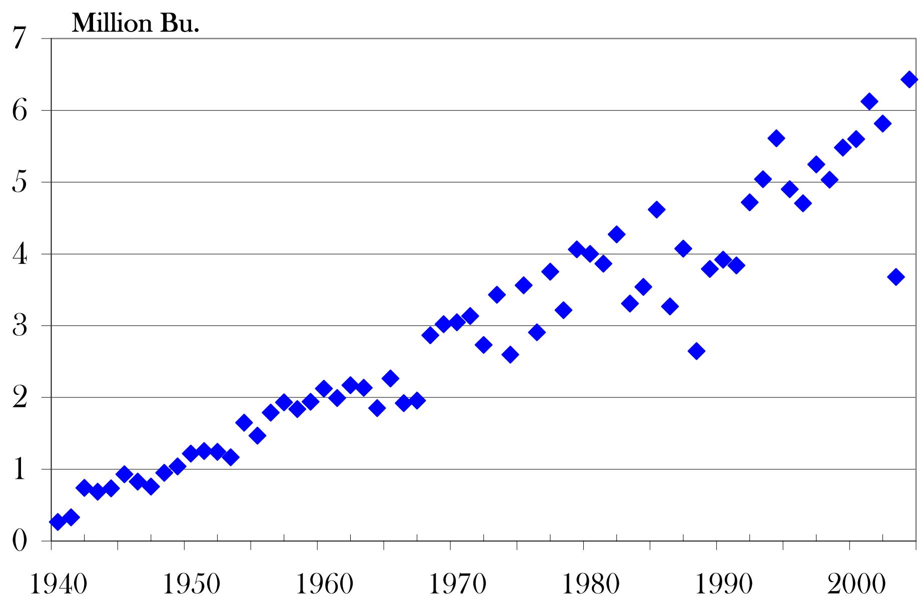

Figure 3.2 White County Soybean Production 1940-2004

3.3 Canola

Another oilseed crop that may have potential for energy production in White County is canola. Spring canola is harvested about the same time as wheat and has never been grown in NW Indiana due to a lack of markets[26]. Canola contains about 40 percent oil and 23 percent protein which is twice the oil content of soybeans[27]. North Dakota variety trials indicate that yields fall between 1,800 pounds and 2,400 pounds per acre[28].

Canola	
2,100	lbs of canola/acre
756	lbs of canola oil/acre
99	gal biodiesel/acre
117,000	BTU/gal
15,400	BTU/lb

[25] Jim Wimberly, BioEnergy Systems LLC, Fayetteville, Arkansas, personal communication 2005.
[26] Gregory Bossaer, Purdue Extension, Reynolds, IN. Personal communication 2006.
[27] E.S. Oplinger, L.L. Hardman, E.T. Gritton, J.D. Doll, and K.A. Kelling. Canola (Rapeseed). Alternative Field Crops Manual. http://www.hort.purdue.edu/newcrop/afcm/canola.html.
[28] North Dakota State University. Roundup-Ready canola variety trial results. http://www.ag.ndsu.nodak.edu/langdon/05data/canola-rr-2.pdf

Based on a yield of 2,100 lbs per acre, 40 percent oil, an oil bulk density of 7.6 lbs per gallon, and 90 percent process efficiency, canola could yield 99 gallons of biodiesel oil per acre. In comparison, soybeans were estimated to produce 63 gallons of biodiesel per acre.

3.4 Dedicated (Cellulosic) Energy Crops

A great deal of analysis has gone into determining the biomass fuel capacity for the US. These studies are based on projections more than historical yield data. Few fiber crops are grown for energy production and little data is collected on the crops that are grown. The biomass energy studies are interesting from an academic perspective, because they allow us a glimpse of what a biorenewable economy will look like.

The USDA/DOE 'Billion Ton' report did a comprehensive analysis of 'if' and 'how much' US biomass could replace our transportation fuels[29]. The report found that 1.3 billion dry tons of biomass could be produced: one billion from agricultural lands and 0.37 billion dry tons from forest lands. The 1.3 billion dry tons of biomass would be sufficient to replace one third of our US demand for transportation fuels by the year 2030.

We produce a great deal more biomass than we know. As illustrated in Table 3.1, already in White County, Indiana nearly 500,000 tons of corn stover is grown – but is not harvested for energy production. A goal of biomass energy advocates is to replace some grain and soybean crop acreage with energy crops. It is not an unrealistic objective, but farmers will want to make as great a return, or more, from their dedicated energy crops as they are making now from the traditional grain and soybean crops.

The 2005 Indiana Renewable Energy Resources Study reports that by planting all agricultural land to switchgrass, 90 million tons of biomass could be produced each year[30]. That is 180 times more than the current volume of White County corn stover. They convert this to an energy value of 1.54 quadrillion BTU/year (a billion million BTUs). But to succeed at growing only energy crops,

[29] Perlack, Robert D., et. al. USDA and DOE. April 2005. (see footnote 5 for complete information).

[30] 2005 Indiana Renewable Energy Resources Study. State Utility Forecasting Group, Purdue University, West Lafayette, Indiana. September 2005. engineering.purdue.edu/IE/Research/PEMRG/SUFG/PUBS/PUBS/2005_Renewables_Final.pdf

the sale of the new energy crops would have to exceed the 2004 value of crop sales in Indiana of $3.7 billion (USDA-NASS)[31]. It may happen at some point, but this will take time.

The simple reason folks get so excited about the production of dedicated energy crops on prime farmland is that on a dry ton basis it is possible to approach three times more biomass than is produced by corn (shelled corn + stover). As energy prices climb the energy market will continue to drive crop planting decisions. A lot has to happen before energy crops become profitable. One challenge is that the processing/conversion technologies must improve.

Dedicated energy crops can be converted into alcohols like ethanol. The cellulose and hemicellulose components of plant fiber are more complicated versions of the five and six carbon sugars (pentose and glucose) currently used to make alcohols like ethanol. They are bound together by another carbon compound, lignin. Lignin is a complex carbon compound that does not break into smaller carbohydrates as easily as cellulose and hemicellulose.

Lignin is the reason that we are not currently using fiber energy crops as frequently as corn is being converted into ethanol. Lignin doesn't work well with the sugar conversion technologies and the process of separating lignin from the simpler sugar compounds generally limits the value of the sugars. Lignin does have value as a fuel and some processes are being developed that allow the less manageable lignin to be utilized on-site as a fuel itself.

The three most significant dedicated energy crops are switchgrass, miscanthus and hybrid poplars.

3.4.1 Switchgrass Much of the existing work on dedicated energy crops has been done with switchgrass. Switchgrass is a perennial crop that utilizes C4 photosynthesis pathways (like corn)[32]. C4 plants utilize solar

Switchgrass	
8,675	BTU/lb
6.0	tons/acre
104.1	MMBTU/acre

[31] USDA-NASS, Indiana State Overview – 2004. http://www.nass.usda.gov/Statistics_by_State/Ag_Overview/AgOverview_IN.pdf

[32] Heaton, Emily, Tom Voigt, Stephen P. Long, 2004. "A quantitative review comparing the yields of two candidate C4 perennial biomass crops in relation to nitrogen, temperature and water. Biomass and Bioenergy 27 (2004) 21-30. Elsevier Ltd.

radiation up to 40% more efficiently than C3 plants (like soybeans). Switchgrass has a deep-rooting rhyzominous structure that has great environmental benefits. Since switchgrass is a perennial crop, there are no annual planting or field tillage operations to manage.

Harvesting energy crops can be a challenge[33]. Energy crops use either large round or square baling technologies, or they are harvested by silage choppers and wagons. Since the energy grasses are harvested at the end of the growing season, they are tall and woody, which adds more difficulty than harvesting green forages.

De La Torre Ugarte et. al, 2003, reports annual switchgrass yields in the Corn Belt at 5.98 dry tons/acre (give or take 0.8 tons/acre)[34]. This report also estimates production costs at $976 per acre, or $18.21 per ton. This 2003 report used the benchmark price of $40 per dry ton established by Walsh et. al, 1999, as the sale price of switchgrass[35]. The De La Torre Ugarte report compared management plans that focused on wildlife development and on production management. They also found that under the assumptions of the report the price of corn increased also.

It is important to reiterate that although these economic analyses are useful tools, there are almost no current markets for switchgrass. There are a few plants that are co-firing biomass with coal, but other than that, all the economic assumptions are constructed based only on the best available information.

Miscanthus	
8,675	BTU/lb
13.0	tons/acre
225.6	MMBTU/acre

3.4.2 Miscanthus New research at the University of Illinois with elephant grass (*miscanthus* x *giganteus*, a sterile hybrid), shows excellent promise as a future biomass energy crop. It grows 10-13 feet tall and

[33] Michael Katterhenry, "Biomass Harvesting" Biomass Energy Crops for Power and Heat Generation in Illinois. University of Illinois. Urbana, IL. January 12, 2006

[34] De La Torre Ugarte, Daniel, Marie Walsh, Hosein Shapouri, Stephen P. Slinsky. 2003. "The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture. USDA and DOE. February 2003. Agricultural Economic Report No. 816.

[35] Walsh, Marie E., Robert L. Perlack, Anthony Turhollow, Daniel de la Torre Ugarte, Denny A. Becker, Robin L. Graham, Stephen E. Slinsky, and Daryll E. Ray. 2000. *"Biomass Feedstock Availability in the United States: 1999 State Level Analysis."* Oak Ridge National Laboratory, Oak Ridge, TN. April 30, 1999, Updated January, 2000. http://bioenergy.ornl.gov/resourcedata/index.html

yields between 10-13 tons/acre[36]. The fact that this plant is a sterile hybrid causes some interesting challenges. First it can only be planted by using a piece of rhizome (root) from an existing plant. According to Heaton et. al, 2004, Miscanthus has been explored as a biomass energy crop in the EU just as switchgrass has been examined as an energy crop in the United States[37].

The University of Illinois is pursuing a number of ways to unlock the genetics of *miscanthus* x *giganteus* to ease propagation and add some genetic stability. Since all the miscanthus plants under cultivation in the US are cuttings from an original parent plant, any kind of pest problem that may arise in the future would impact every plant that is growing today. Even though there are a multitude of challenges remaining to commercialize production of miscanthus (seedstock production, distribution, harvesting technology, processing technology: combustion, gasification, or hydrolysis to alcohol), efforts are underway to develop sufficient root stock to supply commercial production a few years out[38].

3.4.3 Hybrid Poplars Hybrid poplars are likely not high on the list of profitable biomass feedstocks for BioTown and White County, Indiana, but they deserve mention. Like switchgrass, hybrid poplars are recognized for their environmental benefits[39]. Hybrid poplars are a softwood tree that is commercially under production by the pulpwood industry. It is a renewable source of pulpwood and is an excellent source of biomass energy[40]. Hybrid poplars can produce as much as 10 tons per acre of biomass annually. Once a cellulosic energy infrastructure develops for planting, harvesting and processing fiber for energy, hybrid poplars may have appeal for the BioTown area.

Hybrid Poplar	
9,005	BTU/lb
10.0	tons/acre
180.1	MMBTU/acre

[36] Heaton, Emily, et. al., 2004. Biomass and Bioenergy 27 (2004) 21-30. Elsevier Ltd.
[37] Heaton, Emily, John Clifton-Brown, Thomas B. Voigt, Michael B. Jones and Stephen P. Long. "*Miscanthus* for Renewable Energy Generation: European Union Experience and Projections for Illinois." Mitigation and Adaptation Strategies for Global Change 9: 433-451, 2004. Kluwer Academic Publishers. Netherlands.
[38] Caveny, John. 2006. "Miscanthus Commercialization Update." Biomass Energy Crops for Power and Heat Generation in Illinois – Diversifying Cropping, Improving Energy Security and Benefiting the Environment. University of Illinois, Champain-Urbana. January 12, 2006.
[39] Licht, Louis A. and J.G. Isebrands. "Linking Phytoremediated Pollutant Removal to Biomass Economic Opportunities." http://www.ecolotree.com/pdf/5.0504_linkingopportunities.pdf
[40] Gerald Tuskan, "Popular Poplars: Trees with Many Purposes." Oak Ridge National Laboratory. Oak Ridge, TN. http://bioenergy.ornl.gov/main.aspx

3.5 Manure

Swine Manure	
0.9-1.1	MMBTU/hog/year[41]
4,000	MMBTU/4,000-hog house/year
10,000	MMBTU/10,000-hog house/year
150,000	MMBTU in White County/year

Manure has become an underutilized resource. Traditionally, manure has been land applied, but as livestock farms have become larger and more specialized there has been a tendency to focus on the livestock operation and less on the crop nutrient opportunities. *Even so, the economic reality is that as livestock farms have become larger and more specialized there are even more opportunities to utilize a consistent, continuous supply of manure into multiple treatment/processing technologies like biomass energy and composting.*

White County has a great resource in manure. A significant source of farm revenue in White County is from hogs. The 2002 Census of Agriculture reports that 313,131 hogs were sold on 95 farms in White County (Table 3.2)[42]. Ninety-seven percent of the White County hogs (303,089 head) were produced on 50, large hog farms. The average farm sales from these larger farms were about 6,000 hogs per year. That means that locating large quantities of fairly consistent manure supplies will be manageable.

Table 3.2 White County 2002 hog farm and herd size

	All farms	> 1,000 hogs[43]	% of total
White County farms that sold hogs in 2002	95	50	52.6%
Hogs sold on White County farms in 2002	313131	303089	96.8%
Average size herd from farms > 1,000 hogs		6,062	hogs/farm

The predominant hog manure treatment technology is to handle it as a liquid in pits below the houses. Manure is pumped out twice a year, when cropland is available for receiving liquid manure. This is an efficient method for raising hogs. For converting the manure into biomass energy, the manure can be utilized as a liquid feedstock (such as a methane digester). Liquid manure can also be converted to a dry biomass feedstock by drying or separating the solids. The dry biomass conversion technologies include combustion, gasification and pyrolysis.

[41] 0.9 MMBTU based on Fulhage. 1.1 MMBTU based on Moser. 1.0 MMBTU was used for hog building capacity – not total hogs.
[42] USDA 2002 Census of Agriculture, White County, Indiana Hog Production. http://151.121.3.33:8080/Census/Create_Census_US_CNTY.jsp
[43] The largest hog farm category available in the Census of Agriculture was for farms with more than 1,000 head of sales or (> 1,000 hogs). There are likely farms with sales of 10,000 – 20,000 hogs per year, but the closest estimate that can be established is an average of annual hog sales of 6,062 hogs.

One of the challenges of using White County hog manure to power BioTown is that White County is a large place and most of these hogs are more than a few miles from Reynolds. Another challenge is that large hog farms use lots of energy. Most on-farm, manure-derived energy projects provide just a little more electricity than the farm requires. This is a desirable accomplishment, but the large hog population in White County will not automatically provide a complete power solution for BioTown. Only the most efficient farms convert the waste heat from the digester and generator into heat recovery systems. Some farms that capture the methane gas in covered-lagoon digesters 'flare' the gas with an open flame and do not generate electricity.

There is one large beef feeding operation on the north edge of Reynolds. The beef manure is dry and is composted with bedding. The low moisture content of the manure and the added organics from the bedding open up opportunities for utilizing dry biomass energy conversion technologies. In addition to the beef feeding operation this facility also operates a hog facility. The close proximity to Reynolds may open other opportunities to combine the dry, bedded, composted beef manure with other liquid or dry biomass feedstocks from Reynolds.

3.5.1 Manure Quality and Variability Successful operation of a biomass energy conversion technology on a manure-based feedstock requires consistent quantities and relatively consistent qualities. The greater the variability of the feedstock is, the more difficult to maximize the efficiency of the conversion technology. The importance of manure treatment technology on manure quality can be illustrated by looking at the variability of manure nutrients[44].

The variability in manure quality is created from several sources. Feed ration can create variability. The size of hog and stage of life adds nutrient variability. In Figure 3.3 manure nutrients are charted by age and life-stage of hogs for comparison[45]. For the finishing hogs, P2O5 changed little with weight, while N and K2O quantities increased[46]. Gestation reduced all nutrients while

[44] Manure energy and nutrients can be managed separately, but manure energy is even more sensitive to technology than manure nutrients. The nutrient discussion is used here as a proxy for manure energy.

[45] Lorimor, Jeff, Wendy Powers, and Al Sutton. 2004. "Manure Characteristics" MWPS-18 Section 1, Second Edition. Manure Management Systems Series. Midwest Planning Service. Ames, IA.

[46] N stands for nitrogen. P2O5 is phosphorus oxide, but is the historic, legal standard notation for phosphorus which is 44% phosphorus by weight. Similarly, K20 is the historic and legal standard for potassium which is only 83% potassium. N, P2O5 and K2O are the primary manure nutrients of interest for use in crop fertility.

lactating sows increased all nutrients. These and other variations in feedstock quality can be managed, sometimes by selection of a specific bioenery conversion technology (Chapter 5).

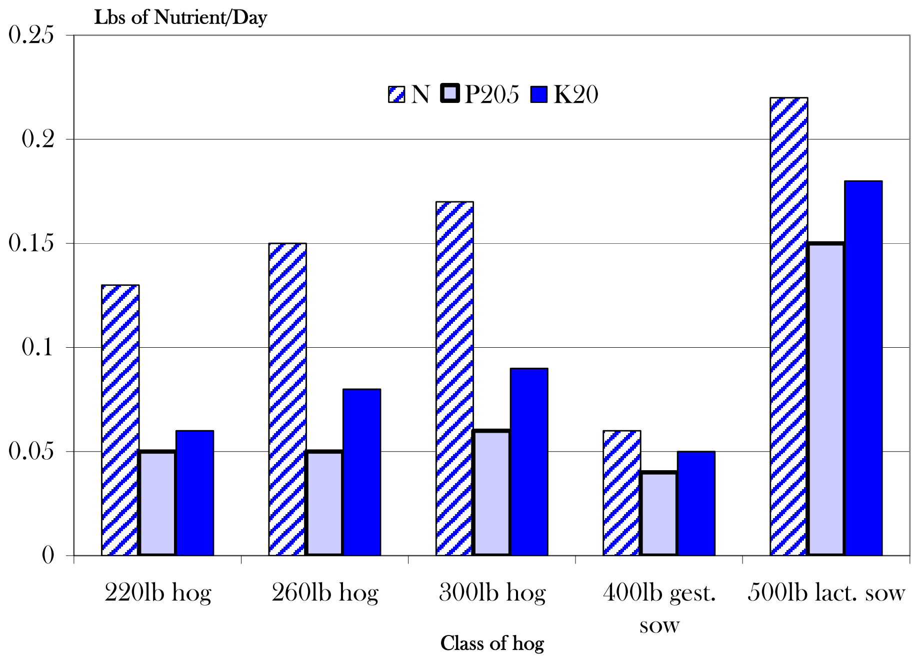

Figure 3.3 Nutrient variability by size of hog (MWPS-18, Section 1)

Treating fresh swine feces with different technologies adds variability to manure. Lorimor and Kohl sampled manure from 183 facilities in Iowa and found that manure treatment system influenced the nutrient content of the manure[47]. Buildings using 'wet/dry feeders' and 'deep pit' technologies conserved nutrients better than other buildings with other concrete and earthen pits. The manure nutrient levels of buildings with wet/dry feeders and deep pits had nearly twice the nitrogen, phosphorus and potassium as manure stored in earthen pit technologies.

The point is that manure has a high degree of variability. In this case, it is easy to this variability using hog manure nutrients and technology as an example. Starting with the same basic fresh manure, different treatment technologies achieved different results. Successful conversion technologies must be designed and managed to remove the variability by segregating non-similar flows or combining them consistently into an aggregate flow. Biomass feedstock variability is a challenge, but it can be managed by system design.

[47] Lorimor, Jeffery C. and Kris Kohl. 1999. Liquid Swine Manure Nutrients. Iowa State University. Ames, IA. ASL-R 1596.

3.5.2 Available Manure Most of the hog manure in White County is several miles from the town of Reynolds. As mentioned above, to the north of Reynolds is a beef feeding operation with a significant hog production facility associated with the beef operation. South of Reynolds within two miles there are three sizable finishing hog operations. The hog operations in White County are reportedly in 4,000 head, 10,000 head and 14,000 head capacities (capacity is not the same measure as annual sales reported above).

3.6 Municipal Sewage/Biosolids

Municipal sewage, if it is primarily residential, is largely organic in nature. The direct association of sewage to human digestive systems makes pathogens and waste carbohydrates that feed the pathogens, the primary concerns of municipal sewage treatment. Generally, cost effective sewage treatment occurs by aeration of the waste, which burns off the carbon (reducing the risk of pollution potential). Once the carbon is stabilized (used up), any pathogens that may remain in the treated waste are killed by a chlorinization process.

Most sewage treatment technologies involve carbon reduction and chemical sterilization. Biomass energy technologies utilize the carbon and generally remove human pathogens at the same time. An added challenge with using municipal sewage as a biomass feedstock is that these materials are heavily regulated. Even so, like the other organic feedstocks, municipal sewage can be a viable biomass energy feedstock. In the Reynolds/BioTown area the human sewage waste/feedstocks that are in significant quantities are Reynolds sewage, Monticello sewage, White County septage (cleanout from septic systems), and restaurant brown grease.

3.6.1 Reynolds Municipal Sewage The Reynolds municipal sewage treatment plant has a design capacity of 800 people with a design flow of 100 gallons per capita per day[48]. The treatment facilities are designed on an influent Biological Oxygen Demand (BOD) of 0.17 lbs/capita/day and Total suspended solids (TSS) of 0.20 pounds/capita/day. The Reynolds plant has a design flow of 80,000 gallons per day.

Sewage	
8,217	BTU/pound
26,000	pounds/year Reynolds
214	MMBTU Reynolds
326,000	pounds/year Monticello
2,679	MMBTU Monticello

[48] Town of Reynolds, State of Indiana, Department of Environmental Management, Authorization to Discharge under the National Pollutant Discharge Elimination System. July 26, 2004.

3.6.2 Monticello Municipal Sewage The Monticello Sewage Treatment Plant has inquired if the sewage in Monticello could be considered a BioTown feedstock. If the proper system could be designed, the additional BOD and TSS from Monticello could be a biomass energy windfall for Reynolds. Monticello has a daily flow of 750,000 to 800,000 gallons per day.

3.6.3 Septic Tank Cleanouts and Restaurant Brown Grease. Godlove Enterprises, Inc. has been contacted about the rural septic tank cleanout material as a biomass feedstock in BioTown, USA[49]. Because this septic tank material has similar characteristics as municipal sewage it can add to the available biomass feedstocks if an appropriate conversion technology is identified.

Septage
8,217 BTU/pound
910,000 gallons/year
7,735,000 lbs (8.5 lbs/gal)
116,025 lbs solids
950 MMBTU/year

Godlove Enterprises, Inc. also cleans out restaurant brown grease traps. Annually about 1.3 million gallons of septage and brown grease are cleaned out. Roughly 70 percent is septage (910,000 gallons) and 30 percent (390,000 gallons) is brown restaurant grease.

Brown Grease	
15,400	BTU/lb[50]
390,000	gallons/year
3,315,000	lbs (8.5 lbs/gal)
49,725	lbs solids
770	MMBTU/year

3.6.4 Used Vegetable Oil and Number 2 Yellow Grease. Although quality and variability issues are real challenges, used vegetable oil and animal fat hold potential for the conversion to biodiesel fuels. While the challenges are real, the quantities and prices paid for the used oil are near zero, relative to virgin vegetable oil. There is a different economic dynamic with used oil.

Yellow Grease	
15,400	BTU/lb[51]
2,843	kg/restaurant[52]
6,269	lb/restaurant
354	restaurants
2,219,161	lbs
34,175	MMBTU/year

A simple query was done of restaurants by town and distance from Reynolds (Table 3.3). This table can be summarized as having 55 restaurants within 10 miles, 70 restaurants within 15 miles, 110 restaurants within 20 miles, and 354 restaurants within 25 miles. It appears that the BioTown

---

[49] Steve Godlove, General Manager, Godlove Enterprises, Inc. Personal communication. December 2005.
[50] Brown Grease BTU/lb = Soybean oil BTU/lb. Estimates varied above and below.
[51] Yellow Grease BTU/lb = Soybean oil BTU/lb. Estimates varied above and below.
[52] George Wiltsee. "Waste Grease Resources in 30 U.S. Metropolitan Areas." BioEnergy '98: Expanding BioEnergy Partnerships. www.biodiesel.org/resources/reportsdatabase/reports/gen/19981001_gen-107.pdf

area may support a pilot-scale used food-grade oil to biodiesel project, but may need to expand beyond the immediate BioTown area to site a commercial scale plant.

Table 3.3 Number of Restaurants by Distance and Town from Reynolds, IN

Average Miles	Town by Zip Code	Number of Restaurants
0.5	Reynolds, IN 47980	4
6.3	Monon, IN 47959	4
7.8	Chalmers, IN 47929	1
9.1	Monticello, IN 47960	46
11.7	Brookston, IN 47923	8
12.4	Wolcott, IN 47995	3
14.8	Francesville, IN 47946	4
16.8	Battle Ground, IN 47920	5
18.4	Delphi, IN 46923	18
18.9	Remington, IN 47977	10
19.4	Burnettsville, IN 47926	1
19.9	Medaryville, IN 47957	6
22.6	Rensselaer, IN 47978	23
23.5	West Lafayette, IN 47906	95
23.5	Demotte, IN 46310	1
24.3	Lafayette, IN 47901, 47903, 47904, 47905	121
24.4	Otterbein, IN 47970	4

3.7 Municipal Solid Waste (Trash)

EPA reports that nationally, per capita MSW generation at 4.3 pounds of trash per day[54]. EPA also reports that for 2003, 65 percent of U.S. Municipal Solid Waste (MSW) by weight, was composed of paper (35.2%), yard trimmings (12.1%), food scraps (11.7%) and wood (5.8%).

MSW	
4,830	BTU/lb[53]
12,700	tons/year
25,400,000	lbs/year
123,000	MMBTU/year

[53] Princeton Energy Resources International, LLC. Preliminary Engineering And Economic Assessment Of Energy Consumption And Renewable Energy Production Potential For Vashon-Maury Island http://www.iere.org/energy/Vashon-Summary.pdf

[54] Municipal Solid Waste Generation, Recycling and Disposal in the United States: Facts and Figures for 2003. EPA. http://www.epa.gov/msw/pubs/msw05rpt.pdf

STATS Indiana reports a 2004 population of White County at 24,846 people[55]. Assuming Indiana per capita waste generation is close to the national average, White County would generate 19,500 tons of MSW per year. Based on the estimated organic composition of this MSW, 65% (of 19,500 tons) is 12,700 tons of biomass that is going into a landfill.

IDEM reports, in 2004, the Liberty Landfill in White County took in a total of 22,388 tons of waste (MSW and Non-MSW – Table 3.4)[56]. This is close to the national average estimate for White County of 19,500. If we consider that all of the White County-generated MSW may not make it into the Liberty Landfill, the national average is not too far from the 17,000 tons reported by IDEM.

Table 3.4 2004 Liberty Landfill, Tons of Solid Waste Received (White County, IN)

County of Origin	Municipal Solid Waste	Other Non MSW	Total
Cook, IL	275,785	15,218	291,003
Tippecanoe, IN	129,677	3,288	132,965
Lake, IN	115,183	11,638	126,821
White, IN	**17,008**	**5,380**	**22,388**
12 Other IN Counties	9,544	1,014	10,558
Totals	547,197	36,538	583,735

An even more compelling point is that of the 583,735 tons of total waste that was taken in by the Liberty Landfill in 2004, only 22,388 tons were from White County. That is less than 4 percent from White County. This is an excellent example of net gains from importing biomass feedstocks.

One final point, in 2005, Liberty Landfill began generating electricity from their methane gas. They have installed 4, 800-kilowatt generators[57]. This produces enough electricity to power 2,600

[55] STATS Indiana IBRC. White County IN Depth Profile. 'STATS Indiana' is an information service of the Indiana Business Research Center at Indiana University's Kelley School of Business and receives major support from the State of Indiana administered by the Indiana Department of Workforce Development http://www.stats.indiana.edu/profiles/pr18181.html

[56] 2004 Summary of Indiana Solid Waste Facility Data. Indiana Department of Environmental Management, Office of Land Quality. http://test.ai.org/idem/risctest/land/sw/facility.asp?id=91-04

[57] White County REMC, August 2005 Newsletter, "The Power of Green." http://www.whitecountyremc.com/newsletter/pdf/WHITEAUG2005.pdf

homes[58]. Personal conversations with different individuals involved indicate they are producing more electricity from the waste gas off the landfill than anyone could have imagined. This is a tremendously exciting use of the landfill resources.

Some biomass energy advocates argue that landfill gas is not the best use of biomass energy resources. This argument is based on the sheer volume of underutilized biomass going into a landfill. Using the EPA breakdown of organic, biomass materials going into a landfill (65 percent), 355,678 tons of the 547,197 tons of MSW entering the Liberty Landfill are biomass feedstocks. Using the value of 4,830 BTU/lb, 356,000 tons of landfilled-biomass materials contain 3.4 million MMBTUs. That is a lot of underutilized fuel. This new separation and energy production process would not be as simple as it sounds and would require significant changes in the current collection system.

3.8 Imports and Exports of Biomass Feedstocks

As mentioned above, biomass feedstocks move into and leave the BioTown area and White County. The Liberty Landfill imports 96 percent of its waste material from outside White County. This is a good thing from the stand point that they are generating enough electricity to power 3.2 megawatts of generating capacity. Transfarm, Inc. is listed with IDEM as a permitted Indiana composting facility. They import clean biomass fiber to make their compost a high quality compost product.

Biomass feedstock materials are also exported out of White County. Permitted land application of septic tank cleanout material is the conventional practice for disposal of this material. When land application is not possible (ground is frozen or wet), Godlove Enterprises, Inc. must export the septic tank cleanout material from White County to the next closest permitted receiving facility in Elkhart, Indiana.

There are benefits to importing and keeping White County surplus biomass feedstocks in the BioTown area and converting them to local, green power.

[58] Wabash Valley Power homepage. http://www.wvpa.com/

3.9 Summary of Available Feedstocks

The individual feedstocks that have been identified in this chapter are summarized in Table 3.5. Based on the current, undeveloped White County biomass production, 16,881,613 MMBTUs are available for conversion into energy. The energy values for soybeans and canola only consider the oil and do not include the valuable protein and fiber of those crops. The swine manure energy is also based on estimates of potential methane gas created. There are other ways to create energy from feces, but they are not presented in this broad overview. All other values in the table represent the Higher Heating Value (HHV) of the raw feedstock.

This local inventory of available biomass feedstocks is a giant leap forward from the conventional pathways and management of organic waste materials. As BioTown projects are implemented even better data can be collected about available feedstocks, including the development of new energy crops and materials. It is common for technology vendors to conduct test burns and trials with samples of materials that will be used in the technology. The realization of BioTown, USA will lead the way for improved, more robust data collection of biomass feedstocks.

Table 3.5 Summary Of Raw Energy Value Of Individual Feedstocks

	Energy	Supply	Yield	Energy yield	Total Energy
Corn – Grain	8,100 BTU/lb	130,000 ac., county	160 bu/acre	72.6 MMBTU/acre	8,000,000 MMBTU
Corn – Stover	7,800 BTU/lb	130,000 ac., county	3.4 tons/acre	59.0 MMBTU/acre	7,700,000 MMBTU
Soybeans*	15,400 BTU/lb	117,700 ac., county	63 gal/acre	7.4 MMBTU/acre	870,000 MMBTU
Canola*	15,400 BTU/lb		99 gal/acre	11.6 MMBTU/acre	
Switchgrass	8,675 BTU/lb		6 tons/acre	104.1 MMBTU/acre	
Miscanthus	8,675 BTU/lb		13 tons/acre	225.6 MMBTU/acre	
Hybrid Poplar	9,005 BTU/lb		10 tons/acre	180.1 MMBTU/acre	
Swine Manure+	650 BTU/cf	150,000 hog capacity	4.5 cf./hog/day	0.9-1.1 MMBTU/hog	150,000 MMBTU
Reynolds Sewage	8,217 BTU/lb	26,000 lbs, Reynolds			214 MMBTU
Monticello Sewage	8,217 BTU/lb	326,000 lbs, Monticello			2,679 MMBTU
Rural Septage	8,217 BTU/lb	910,000 gallons, county			950 MMBTU
Brown Grease	15,400 BTU/lb	390,000 gallons, county			770 MMBTU
Yellow Grease	15,400 BTU/lb	2.2 mil. lbs, 354 restaurants			34,000 MMBTU
MSW^	4,830 BTU/lb	12,700 tons, County			123,000 MMBTU
Total Energy					**16,881,613 MMBTU**

** Soybeans and Canola are based on the energy value of the oil alone. All energy values except manure are based on the HHV of the raw materials.*

+ Swine manure BTUs are based on the energy value of the biogas/methane, not the HHV value of the raw manure.

^ Municipal Solid Wastes (MSW) energy values are based on the estimation of direct combustion of White County trash generation. It does not include the energy value of the methane gas currently produced at the Liberty Landfill in White County. In 2004, White County MSU accounted for about 5% of material entering Liberty Landfill.

4 Biomass Energy Conversion Fundamentals

4.1 Biomass Chemistry

Biomass is recently generated plant material. Biomass materials are separated from prehistoric plant-derived products like coal and crude oil. Biomass includes virgin plant products like grains, grass and wood, and processed plant material like paper, manure (unused corn and soybeans), and other plant-based wastes and residuals. Conceptually, biomass chemistry is not complicated. This brief discussion targets the conceptual level of biomass chemistry.

4.1.1 Understanding Carbohydrates and Other Carbon-Based Molecules. Carbohydrates, CHO, store energy in plant and animal life. They include the sugars, starches and fibers. Sugars form a basic carbohydrate unit. Starches and fibers are polysaccharides (many sugars) because they are formed from multiple combinations of simple sugars and other molecules.

Sugars can have a different number of carbon molecules. Glucose is a six carbon sugar. Pentose is a five carbon sugar. These five and six carbon sugars are simple sugars or monomers (a single unit). They also have different shapes. Glucose and fructose are 6 carbon sugars, with a different configuration of the 6 carbon, 12 hydrogen and 6 oxygen molecules. Sucrose is composed of a glucose sugar plus a fructose sugar (less a water molecule).

As mentioned earlier, starches and fibers (like cellulose) are combinations of either the same molecule of sugar, or they are combinations of different kinds of sugars[59]. The starches are much smaller molecules than the cellulose and hemicellulose molecules. Cellulose and hemicellulose molecules are the carbohydrates in fiber. Cellulose is composed of like sugar molecules. Hemicellulose is similar to cellulose, but is composed of multiple sugars. The fact that these larger carbohydrate molecules are made from various combinations of sugars is beneficial when trying to reduce them back down into sugars.

[59] Brown, Robert, Biorenewable Resources: Engineering New Products from Agriculture. Iowa State Press. Ames, IA 2003.

The third principle carbon-based component of these larger fibrous carbohydrates is lignin. Lignin is not a carbohydrate and is not composed neatly of different kinds of sugars. Lignin is not easy to separate from cellulose and hemicellulose. It is the biological glue that holds cellulose and hemicellulose together. Lignin is carbon-based and can be used to some degree as a biomass energy fuel. Generally speaking, efforts to purify cellulose and hemicellulose by removing the lignin often corrupt access to the sugar molecules also.

Other important carbon-based, non-carbohydrates are proteins and fats. Proteins are carbon-based but contain nitrogen. They contain some stored energy, but technically they are not carbohydrates. Similarly, fats and oils also contain significant energy and play an important role in biomass energy production. Technically, they are not carbohydrates either.

And as mentioned in Chapter 1, hydrocarbons are similar in function to carbohydrates, but may lack an oxygen molecule. Hydrocarbon chemistry is well understood and is the conventional language of the fossil fuel energy system. Early efforts to transform biomass into energy have been tied to converting carbohydrates into hydrocarbons, which can be an energy intensive process. In time, biomass energy technologies may rely less on hydrocarbon chemistry.

4.1.2 Hydrolysis – Turning It All to Sugars. Hydrolysis is the process of breaking longer-chain carbohydrates (polysaccharides) into smaller carbohydrates, and eventually into simple sugars. It is based on passing hydrogen (like water, H2O) over the carbon-based materials and so it is called, hydrolysis. Advancements in hydrolysis through the development of new enzymes, chemical, and physical processes are creating opportunities to convert large cellulose molecules to simple sugars.

Hydrolysis is most important for those energy conversion technologies that rely on sugar. If biomass energy conversion shifts away from hydrocarbon chemistry, hydrolysis of complex carbohydrates may play less of a role (see the discussion in Section 1.2.3 of Chapter 1). Today, hydrolysis is an important concept to understand.

4.1.3 The Thermodynamics of Chemistry. It is important to recall that the carbohydrates and non-carbohydrates in this biomass energy discussion are rooted in balanced chemical equations.

The equation related to photosynthesis in Chapter 1 is based on the balance of electrons and chemical bonds before and after the exposure to solar photons.

One of the fundamental pathways in transporting chemical energy is the synthesis of ATP (adenosine triphosphate) from ADP (adenosine diphosphate) and another phosphate[60]. Respiration frees the energy and shifts the ATP molecule back to an ADP molecule. It is the thermodynamics of biochemistry that transfers the stored solar energy as biomass chemical energy.

It is also important to point out that biomass chemistry is primarily the chemistry of carbon, hydrogen, oxygen, nitrogen (proteins) and phosphorus. Balancing these relationships is the key to turning surplus nutrients and organic wastes into valuable biomass energy products.

4.2 Biomass Physics

Biomass has specific physical characteristics that are not difficult to understand and need to be reviewed. These include the affect of moisture content on combustion and the steps involved in the process of combustion.

4.2.1 Moisture and Combustion. Biomass feedstocks, by their biological nature, have a moisture content associated with them. In the field, crops are dried to the extent that time and weather permit. Waste materials on the other hand, are often handled with water added for conveyance. There are efficient livestock production systems based on liquid manure handling technologies as well as efficient production systems that handle manure as a drier material.

When combusting biomass feedstocks to produce energy, the amount of energy used to prepare the feedstock for conversion to energy, should be as small as possible. By definition, a *calorie* is the amount of energy required to raise 1 gram of water, 1 degree Celsius[61]. It takes energy to remove water. The greater the energy used to prepare the feedstock the less net energy that can be

[60] Darnell, James, Harvey Lodish and David Baltimore, Molecular Cell Biology 2nd Ed., Scientific American Books. New York. 1990 p. 37.

[61] We generally think of calories in the context of dietary energy. Industrial energy is generally discussed in terms of joules. 1.0 calorie = 4.187 joules. The other energy convention is British Thermal Units (BTU). This Sourcebook includes all energy units in BTUs or million BTUs (MMBTU). 1.0 BTU = 1055 joules.

generated. Combusting materials that are not dry do not burn as well and increase the water content of the resulting fuel – which is undesirable.

Moisture can be problematic in the transportation of the biomass feedstock. The higher the moisture content the more costly it is to transport, if the water itself is not used for conveyance. Water is added to liquid manure systems to aid in the transport of materials around the facility. Water is also added to sewage to assist in material transport. These are system design criteria and must be considered when assessing biomass utilization.

The presence of water or liquid feedstocks does not eliminate a feedstock from useful energy production. Anaerobic digesters operate on liquid feedstocks. Digesters strip off the methane (CH4), retaining the nutrients and the moisture in the remaining effluent. As mentioned above, one of the constituents in the biogas coming off of anaerobic digesters is water. This water limits the utilization of the biogas generally to on-site uses. The raw gas is not easily compressed or transported off-site.

4.2.2 Burning Biomass. Combustion is more involved than simply starting a fire. Brown (2003) describes combustion as a four step process: heating and drying, pyrolysis, flaming combustion and char combustion (Figure 4.1)[62]. All four steps can occur very rapidly. So these four steps are a bit like a time-lapse image for the mind. Understanding these four steps helps understand the thermal conversion technologies discussed in Chapter 5.

Process of Combustion

Heating and Drying. As heat enters the solid fuel, water is driven off. The next phase, *pyrolysis* can not begin as long as the water remains.

Pyrolysis. Elevated temperatures decompose organic compounds into volatile gases including: carbon monoxide, carbon dioxide, methane, and other compounds that condense into tar when cooled. The resulting char is more porous.

Flaming Combustion. The introduction of oxygen (oxidation) ignites the volatile gases of *pyrolysis*. The ultimate products are carbon dioxide and water, but in the process many intermediate

[62] Brown, Robert, Biorenewable Resources: Engineering New Products from Agriculture. Iowa State Press. Ames, IA 2003. Chapter 6.

compounds combust. When conditions are right, the intermediates will be consumed in the process[63].

Char Combustion. The solid core is oxidized in the last phase. Under optimal operating conditions, char combustion produces carbon monoxide and carbon dioxide.

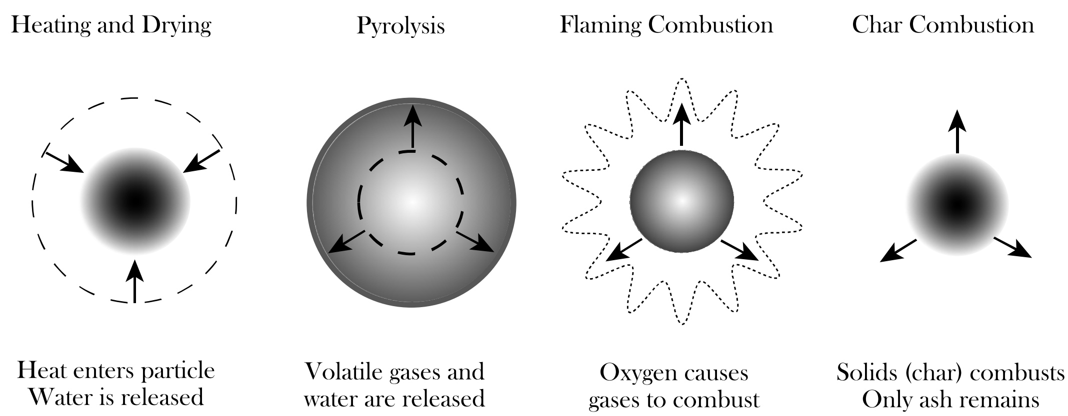

Figure 4.1 Process Involved in Solid Fuel Combustions (Adapted from Brown)

4.3 Biomass Economics

Biomass energy does not have a developed economic infrastructure, so there are a few caveats that describe biomass economics. These relate to economies of scale and scope, the relative nature of prices, feedstock variability, and balancing all enterprises in a total system.

4.3.1 Economies of Scale and Economies of Scope. The term, *economies of scale,* is a relative familiar term related to a firm's ability to gain from specialization. By specializing, firms get larger and spread capital investments over more units of production output. The result is a lower per-unit cost of production and more competitive cost structure. In agriculture we talk about farms getting larger and fewer in numbers. This is due to economies of scale.

The term, *economies of scope,* is the converse of economies of scale. Economies of scope indicate gains from diversification, or the ability to produce multiple outputs from the same asset. A simple example can be illustrated with farm tractors. Tractors connect to various implements and provide multiple uses for the same basic investment. Another example would be meat

[63] Incomplete combustion, due to improper design or management, can produce toxic pollutants.

packing plants. Livestock enter and multiple meat products leave. Meat packers have become very sophisticated over the years providing not only the standard cuts, but new products for new markets and different clients from the same facility.

Livestock facilities have almost been vilified for being large enough to be classified as a Concentrated Animal Feeding Operation (CAFO). There are significant economic gains to becoming larger and very specialized in say, hog production. To develop biomass energy opportunities as well as other new markets, the challenge is to get multiple products from a fixed investment in their assets. In addition to producing finishing hogs, they may need to also produce energy and composted plant nutrients as well as other new markets from the same basic facility.

The good news is that economies of scale (large and specialized) can work together with economies of scope (multiple outputs). The prime targets for manure anaerobic digesters are the large dairies. They have the large volume of easily digestible manure feedstocks. It is not uncommon on large efficient, specialized farming operations to nest lesser enterprises within the umbrella of the specialized enterprise to more completely utilize farm resources.

Economies of scope imply that the sum of the total system is greater than the sum of the parts (individual enterprises).

4.3.2 All Prices Are Relative. This is always true in economics. It is even more apparent in emerging market structures that do not have robust daily prices. Most biomass energy economic studies have been conducted by modeling a stand alone enterprise. The economics tend to reflect the retrofitting of an existing facility with new equipment, using product prices based on a similar existing market. These economic studies are excellent first steps into an industry that barely exists.

All studies are most relevant the minute they are complete. The more time that passes for most price-based economic studies, the less relevant they become. The anaerobic digestion studies done 20 years ago have little economic value today. For one thing, the livestock we are producing today are more efficient at converting feed to meat than they have ever been. We produce less manure per animal than we did twenty years ago. And in the case of anaerobic digesters, the digesters being installed today operate more consistently than the earlier digesters.

In addition, biomass energy studies conducted on an energy price assumption tied to $40 a barrel crude oil, will have a significantly different result when crude oil sells for $60 or $70 a barrel.

All biomass energy markets must be contractually established or used internally at the production site. There are no terminal markets (grain elevators or stockyards) for a producer to deliver a load of biomass energy to sell. This is a profoundly different marketing strategy than existed for grain and livestock 50 years ago. If a facility intends to develop a biomass energy or alternative market, it must first find a buyer/client – and sign a contract.

4.3.3 Feedstock Variability (Quality and Quantity). Energy buyers (liquid fuel, natural gas, or electricity providers) can not serve their customers if both the product quality and product quantity are not consistent. It may be difficult to supply a biomass energy plant with a consistent quantity of feedstocks 365 days per year if the materials are only available seasonally. Likewise an electric utility can not provide reliable electricity to their clients if the product they receive from a biomass energy facility varies in quantity and quality.

4.4 Non-energy Biomass …or Summing the Parts of the System

We are taught by the scientific method to isolate one variable to test a hypothesis. Engineers focus on designing one step at a time. Economists focus on specialization (economies of scale), because the mathematics are manageable. Analysis is often based on an enterprise basis and summed to assess the system. Biomass energy system success depends on efficient utilization of all the inputs (feedstocks) and outputs (energy and otherwise).

Biomass energy projects often have such marginal returns that unless all the products and byproducts are utilized, the net returns for the system will not be positive. If an anaerobic digester is the biomass energy project focus, the project will not succeed unless there is a plan to effectively utilize the digested effluent leaving the digester. The effluent has had the carbon stabilized, the odors reduced, pathogens killed, but it contains nearly all of the nutrients that were in the manure and they are in a form that makes them more available to plants. Without another phase planned for effluent utilization, the nutrient-rich effluent will be a greater water quality problem than just managing the untreated liquid manure.

John Motloch describes a similar situation in a case study of the Milligan Bio-Tech Inc. of Saskatchewan, Canada[64]. Milligan Bio-Tech is an innovative community-owned agribusiness venture added value, reduced risk, enhanced energy production, and enhanced environmental performance. Similar innovative thinking can produce integrative eco-economic solutions, enhance quality of life, and shift Reynolds to 100% biorenewable energy.

"In the case-study, local farmers grew canola seed as a food-grade, clear canola oil for the food industry. In any given production year, weather conditions could cause the seed to produce off-color oil unacceptable to the market. This produced major financial hardships. Innovative thinking in the community led to creation of Milligan Bio-Tech, Inc. as a pathway to diversify markets, thereby reducing economic risk (Figure 4.2, W.H Kemp, 2004)."

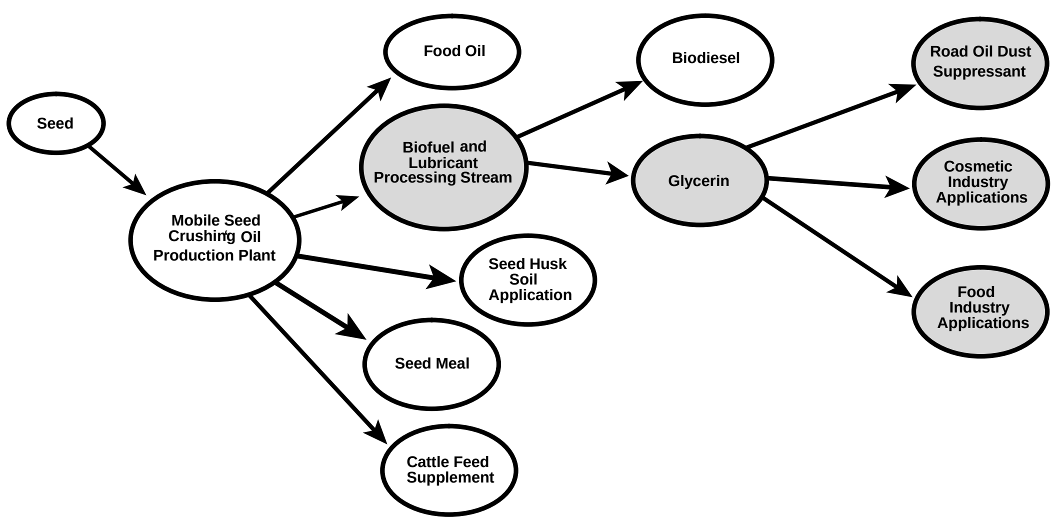

Figure 4.2 Milligan Bio-Tech Canola Production (value-adding eco-economic diversification)

[64] John Motloch, Director, Land Design Institute, Ball State University/BioTown Task Force Member. Paraphrased from "Innovation and the New Economy," Prepared for BioTown Task Force. November 18, 2005. Text in quotations taken from BioTown project proposals. The Milligan Bio-Tech discussion and drawing are based on Smart Power: An Urban Guide to Renewable Energy and Efficiency by William H. Kemp, Aztext Press, 2004.

While only a partial list, non-biomass energy topics of crop fertility, soil amendments and compost; building materials; and industrial chemicals and products, are discussed below.

4.4.1 Crop fertility, Soil Amendments and Composting One of the great 'undersights' of the commercial U.S. livestock industry has been neglecting the impact of under-managed, under-utilized manure nutrients. As the livestock facilities grew in size and concentration over the last three decades, the accumulation of under-managed nutrients became very significant. Over the last five years, federal, state and local governments, in addition to the livestock industry and environmental groups have invested millions of dollars negotiating for new laws. The BioTown, USA solution, which is full utilization of all manure products with simultaneous economic and environmental gains, slipped through that policy process -- undeveloped.

Nutrients (traditional uses) – Manure nutrients have always been utilized in crop fertility programs. In the US since WWII, commercial fertilizer has been cheap and easy to manage. In most areas of the country, crop production has become less connected to livestock production, and manure utilization has been less intensively managed. Discussions with White County farming leaders appear that manure nutrients in the BioTown area are an important part of crop nutrient programs. Even so, there are likely opportunities to increase the intensity of land applied organic nutrients in crop production.

Added pressures from forecasted record high fertilizer prices in the spring of 2006 could draw competition for manure nitrogen supplies in crop fertility programs away from biomass feedstock energy opportunities. Biological technologies such as anaerobic digestion and composting conserve the biomass nitrogen much better than the thermal gasification and combustion technologies. Most biomass energy conversion technologies preserve the phosphorus in the conversion byproducts.

Nutrients (new uses) – Just as the opportunities for revenue from biomass energy are rapidly evolving, so are new markets for composted materials. Residential construction has gained a new appreciation for compost in establishing yards for new housing. Also state and federal transportation agencies are using compost to remediate erosion and water quality regulations on road construction sites. These new uses are rapidly increasing the demand – and the value of consistent, quality composted products.

4.4.2 Building Materials: Resins, Fibers and Composites The fibrous nature of biomass can not be overlooked. Wood composites like plywood and fiberboard are low-cost, durable building materials. Use of plant fibers for traditional fiber uses is expanding for ropes and twines using both traditional and new fiber crops[65]. Deland Myers has conducted research at Iowa State University looking at resins and composites from plant proteins and fibers.[66] Dr. Myers work includes using manure as both fiber and a binder for the fibers in the composite. Other research has been conducted in biocomposites at the University of Maine by Stephen Shaler[67].

Dr. Shaler lists Non-Structural Biomass Panel Attributes as:

- Medium Density Fiberboard, Particleboard, Strawboard
- Used where reduced moisture resistance is needed
- Produced using compression molding
- Dry process
- 3-10% adhesive based on dry material weight

The use of biomass fibers has been applied in Indiana also. John Motloch has been involved with nearly a dozen buildings made of straw bales in Indiana[68]. Straw bale construction has cost savings in construction and energy conservation once built. The use of renewable fibers like straw reduces the demand for conventional forest products in building construction.

Finally, Craig Shore, President of Creative Composites, Brooklyn, Iowa, is building his company on the market for light, sound-dampening insulating biocomposites (Figure 4.3)[69]. In addition to

---

[65] Shri Ramaswamy, "Natural Fibers Application and Composites - Potentials for Alternative Non-Wood Fibers." ISU, Growing the Bioeconomy, Ames, IA August 30, 2005. http://www.valuechains.org/bewg/Conf2005/Presentations/Shri_Ramaswamy.pdf

[66] Teddi Barron. "From cow chips to cow barns" Inside Iowa State. May 19, 2000. http://www.iastate.edu/Inside/2000/0519/cowchips.html

[67] Stephen Shaler, "Natural Fibers and Composites." ISU, Growing the Bioeconomy, Ames, IA August 30, 2005. http://www.valuechains.org/bewg/Conf2005/Presentations/Stephen_Shaler.pdf

[68] John Motloch, Director, Land Design Institute, Ball State University/BioTown Task Force Member. Paraphrased from "Straw-based Eco-economic Development," Prepared for BioTown Task Force. November 18, 2005.

[69] Craig Shore "Commercialization of Natural Fiber Composites." ISU, Growing the Bioeconomy. Ames, IA. August 30, 2005. http://www.valuechains.org/bewg/Conf2005/Presentations/Craig_Shore.pdf

building the infrastructure and market for the biocomposites, their long-run business plan also includes building a market and production capacity for kenaf[70].

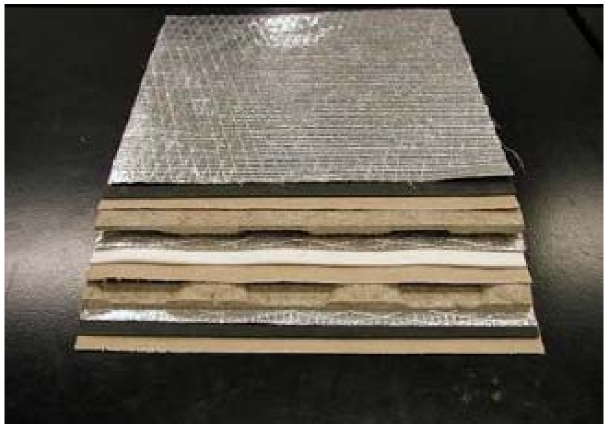

Figure 4.3 Biocomposites from Creative Composites of Brooklyn, IA

4.4.3 Industrial Chemicals and Products Just as with the use of biomass materials in building and construction, chemicals and industrial products are already being made with bio-based products. Robert Brown lists the top 60 organic chemicals with the implication that this is a target list of products that can be made from biomass materials.[71] Table 4.1 is a much broader list of product categories from the Guidelines for Designating Biobased Products for Federal Procurement[72]. This federal rule-making process was part of a federal policy to procure supplies that made from bio-based material and meet specific criteria. Subsequent final regulations no longer follow this initial list, but the process continues to move individual biobased products along towards final federal regulations.

These commercial opportunities are manifesting themselves in Indiana, with companies like the Solae Company of Remington, Indiana which makes textured proteins, concentrates and polymers (plastics) from soybeans. Also Eli Lilly a large pharmaceutical firm in Indianapolis, Indiana.

---

[70] A new annual fiber crop called kenaf, *Hibiscus cannabinus* L, http://www.hort.purdue.edu/newcrop/proceedings1993/v2-402.html

[71] Brown, Robert, Biorenewable Resources: Engineering New Products from Agriculture. Iowa State Press. Ames, IA 2003. Table 5.4. Page 127-128.

[72] Guidelines for Designating Biobased Products for Federal Procurement. Federal Register: December 19, 2003 (Volume 68, Number 244).

Table 4.1 Proposed Categories for Federal Bio-Based Product Procurement

	Minimum biobased content (%)		Minimum biobased content (%)
Adhesives Category		Adhesive products	70
Construction Materials and Composite			
Construction material	85	Insulating foams and films	15
Composite panels	70	Components of mixed system products	20
Molded reinforced composites	10		
Fibers, Paper, and Packaging Category			
Fibers	90	Coated printing and writing papers	20
Fibers composites	30	Bristols	50
Composite packaging materials	30	Newsprint	20
Woven fiber products	75	Sanitary tissues	30
Packaging materials	80	Paperboard and packaging products	30
Uncoated printing and writing papers	20	Other paper products	50
Fuel Additives Category			
Solid fuels	5	Liquid fuel additives	80
Landscaping Materials, Compost, and Fertilizer Category			
Landscaping materials	100	Fertilizer	80
Compost	100		
Lubricants and Functional Fluids Category			
Crankcase oils (water cooled engines)	10	Metal foundry and mold release	50
Crankcase oils (air cooled engines)	50	Transformer oil and dielectric fluids	70
2-cycle engine oils	50	Automotive and other metal complex grease	25
Fifth-wheel grease	40	Total loss lubricants (wire rope, bar-chain, etc.)	50
Turbine and other industrial lubricants	50	Hydraulic, power steering, transmission fluids	50
Penetrating oils	50	Cutting, drilling, and tapping oils (neat use)	50
General purpose and other	90	Metal working concentrates (for dilution)	30
Brake fluids	20	Forming pastes and extreme pressure stamping	30
Concrete and asphalt release	70		
Plastics Category			
Biodegradable foams	50	Water soluble polymers	50
Durable foams	15	Compostable molded products	75
Biodegradable films	25	Molded composites/biobased fibers	20
Durable films and coatings	20	Synthetic fibers	50
Molded plastics and composites/biobased resins	10		
Paints and Coatings Category			
Formulated product	20		
Solvents and Cleaners Category			
Formulated product	50	Neat product (concentrate)	100
Sorbents Category			
Sorbents	90	Sorbent systems	75
Plant and Vegetable Inks Category			
News inks—black	40		
News inks—color	30		
Sheet-fed inks	20		
Forms inks	20		
Heat-set inks	10		
Specialty inks	20		

4.5 Economics of Reuse

Finally, there are two issues of resource conservation and reuse that need to be addressed. They are the price impact of recycling and the value of improving energy efficiency.

4.5.1 The Price Impact of Recycling Recycling enhances efficiency, but it is not without its impacts. In the case of paper recycling, increased efficiencies gained by salvaging used paper created a greater supply of paper from the original supply of pulp wood. The excess supplies of waste biomass feedstocks exist because these waste materials are under developed and so they have a negative value. As new uses for our surplus biomass feedstocks increase, it should also increase the value of those feedstocks, but will lower output prices for the products they displace.

Inputs will have more competition. Corn for ethanol, for instance may get more expensive if corn for animal feed becomes less available. As energy, chemicals and fiber products become more reliant on biomass feedstocks as inputs, each energy-producing firm will compete for the least cost input into the process, driving biomass feedstock prices down. The fact that these last two sentences directly contradict each other is just part of the challenge of establishing a bioeconomy.

4.5.2 Value of Improving Energy Efficiency Little has been discussed here about the value of energy efficiency in BioTown, but its value can not be understated. The federal and state governments as well as the utilities have conservation programs in place. Reducing energy demand by insulation, better sealing windows, more efficient appliances and lighting, will lower the amount of biomass energy needed to replace the current fossil fuel energy used in BioTown. John Motloch has proposed a training workshop in the information he prepared for BioTown in November. His training workshop proposal is entitled, "Home Retrofit Training Workshop."

5 Biomass Energy Conversion Technologies

The biomass conversion technologies are where the feedstocks and conversion science come together. Part of the challenge of producing biomass energy, is that the feedstocks and technologies don't fit together neatly. As discussed in Chapter 4, there are always multiple outputs, and, they change depending on the feedstock. Successful biomass conversion technologies will manage the energy products and the co-products effectively.

The biomass technology discussion gets more complicated because some conversion technologies complement each other. Biomass gasifiers generate process heat in addition to the producer gas and ash that come out of the gasifier. Efficient operation of the gasifier will include a productive use of the residual process heat.

After a brief discussion about ***biomass feedstock handling and storage***, specific biomass conversion technologies are described. The technologies that are discussed here begin with thermal conversion technologies: ***combustion***, ***gasification*** and ***pyrolysis.*** Biological conversion technology of feedstocks to methane gas through ***anaerobic digestion*** is discussed, followed by ***fermentation and distillation*** of ethanol, ***chemical conversion of biodiesel*** and finally ***hybrid systems*** that establish a suite of technologies in interesting ways to convert organics into fuel and power.

5.1 Biomass Feedstock Handling and Storage

Because solid biomass feedstocks are less dense than coal, they require a greater volume to achieve the same level of power as coal. Transportation costs and storage requirements are greater for biomass fuels. The (1.5 MW-size) Coaltec Energy USA gasifier for instance requires 2 tons of biomass per hour (17,500 tons per year)[73]. The much larger Alliant Energy 726 MW Chariton Valley power plant, which is preparing to co-fire with switchgrass has co-fired at rates as high as 16.8 tons per hour (147,000 tons per year)[74].

---

[73] Coaltec Test Burn Demonstration, Carterville, IL. November 17, 2005.

[74] Bill Morton. "Co-firing a Power Plant with Switchgrass." BioCycle Renewable Energy Conference. Madison, WI. September 2005. http://www.jgpress.com/Energy05/Morton_T.pdf

The smaller annual use of 17,500 tons per year is the equivalent of 35,000 large round bales weighing 1,000 pounds each. The larger volume for the Alliant Energy plant would require the equivalent of 300,000 large round bales at 1,000 pounds each.

The Alliant Energy plant has developed a 'collection and storage' system that automates the removal of large square bales from semi-trucks and feeds them into a grinder in preparation for blending with coal.

The fluid nature of liquid biomass feedstocks can be utilized in conveyance, but when these materials must be hauled more than a mile or two, the liquid becomes freight. Most liquid feedstocks will need to have a biomass conversion facility on, or near, the site where the material is produced.

5.2 Combustion

Combustion is the burning of organic material in the presence of oxygen creating a flame. Wood stoves, fireplaces, and industrial burners are examples of biomass energy by combustion.

Even though every residence has a furnace, economies of scale still apply to traditional fireplaces and furnaces. It is less expensive per unit of output to build a large industrial furnace than to build a small residential furnace. Residential homes don't need an industrial furnace though, so there is a demand for small scale units as well as the large, more efficient units.

5.2.1 Small-scale furnaces (heat) The demand for residential corn-burning stoves and furnaces is much higher than the supply. Stoves and furnaces cost between $2,800 and $3,200. According to the December 15, 2005 Wall Street Journal, sales of corn stoves have doubled every year for the last five years. In 2005, about 30,000 wood stoves were purchased. The most attractive aspect of the corn stoves and furnaces is that shelled corn is very cheap. In the Reynolds area it can cost as little as $300 a winter to heat a home[75].

[75] Ben Woodhouse, Reynolds, IN resident and corn stove owner, personal communication, Nov. 2005.

Dennis Buffington, an agricultural engineer at Pennsylvania State University, maintains a website with very useful information regarding burning shelled corn in furnaces and stoves[76]. Based on the heating value, shelled corn is compared to other traditional fuels in Table 5.1. The futures price of coal presented in Chapter 2 is under $60 per ton, so it costs considerably less per ton than shelled corn. Corn burns much cleaner and produces less ash/cinders than burning firewood or coal.

Table 5.1 Shelled corn equivalent of traditional fuels based on heating value (Buffington).

Current Fuel	Equiv. Shelled Corn (lbs)	Equiv. Shelled Corn (bu.)	Cost at $1.85/bu	Cost at $2.50/bu
1 ton of hard coal	3,360	60.0	$111.0	$150.0
1 gallon of #2 fuel oil	22	0.4	$0.7	$1.0
1 million BTUs of natural gas	170	3.0	$5.6	$7.6
1 gallon of propane	15	0.3	$0.5	$0.7
1 full cord of firewood	2,800	50.0	$92.5	$125.0
1 ton of wood pellets	2,575	46.0	$85.1	$115.0
1,000 kWh of electricity	635	11.3	$21.0	$28.4

A few months ago natural gas prices were at $15 per million BTUs or $1.50 per therm[77]. Shelled corn at the same time has been selling at a price near $1.85 per bushel. At these prices, Dr. Buffinton's EnergySelector indicates that burning shelled corn makes more economic sense than burning natural gas (Figure 5.1)[78]. However with natural gas prices recently at $8.215 per MMBTU (1/20/06), and corn prices edging up, the trade-off between shelled corn and natural gas is closer to the decision line of the EnergySelector.

Most corn stoves and furnaces also burn pelleted fuels. These are typically made of waste wood and sawdust. Warming Trends, Inc. lists eight pellet manufacturers, the foundation material used in the pellets, and the heating value range in BTUs for each brand of pellet.[79] The price of the pellets, as posted on their site, ranges from $109 per ton to $160 per ton. For comparison corn at $1.85 per bushel is $66 per ton and corn at $2.50 is $89 per ton.

[76] Burning Shelled Corn as Fuel, Energy Strategies, Penn State University. http://energy.cas.psu.edu/burncorn/shellcorn.html

[77] A 'therm' = 100,000 BTUs = 100 cubic feet of natural gas.

[78] EnergySelector, Penn State University. http://energy.cas.psu.edu/energyselector/

[79] Warming Trends, Inc. http://www.warmingtrendsstoves.com/fuel.html

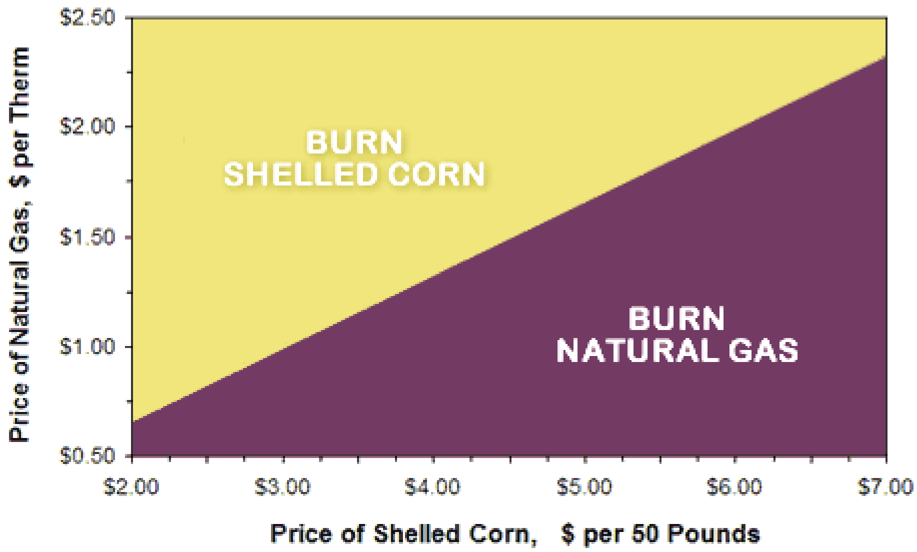

Figure 5.1 Penn State EnergySelector Comparison of Natural Gas and Shell Corn

In addition to wood pellets and corn, pelleted fuel is also made from paper. Paper pellets, as described by the Wisconsin Energy Bureau, are ¾ inch-diameter and 2.5 to 3 inches in length (Figure 5.2)[80]. They range in heating value from 8,500 – 11,500 BTUs.

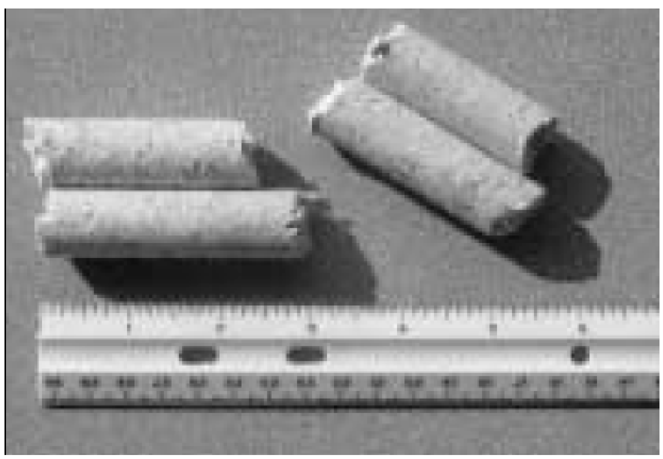

Figure 5.2 Paper Pellet Fuel (WI Energy Bureau)

5.2.2 Large-scale biomass furnaces (heat) Large-scale furnaces and boilers that are powered only by biomass are generally located near surplus, waste biomass fuel supplies. Some paper and lumber mills use their waste wood and paper as on-site energy sources. There is a growing

[80] "Paper Pellets for Industrial Fuel," Wisconsin Energy Bureau. Wisconsin Focus on Energy www.focusonenergy.com/data/common/dmsFiles/W_RB_MKFS_Paper%20pellets%20indust%20fact%20sheet.pdf

biomass furnace and boiler industry to provide on-site heat from biomass fuels. Just as the natural gas prices are sending the residential customers looking for alternative biomass fuels, the same is happening in small industry.

5.2.3 Large-scale biomass power plant (heat & electricity) Single biomass feedstock power plants are not common. Two commercial power plants that are either under construction or consideration are a 55MW Fibrominn power plant and a 20 MW Rahr Malting power plant. Both are located in Minnesota.

Fibrominn – Benson, Minnesota. One biomass power plant that has gained some notoriety is the Benson, Minnesota, Fibrominn power plant. When construction is finished this 55 MW power plant will be powered by 700,000 tons per year of turkey litter[81].

This technology has been commercialized in Great Britain by Fibrowatt, the parent company of Fibrominn. Fibrowatt currently operates four poultry manure-powered plants with a combined generating capacity of 99 MW. In 1998, the U.S. poultry industry was under intense political pressure to modify their manure handling practices. Shortly after that Fibrominn was created. When completed the Fibrominn plant will be the largest plant in operation using the Fibrowatt technologies.

Minnesota has a large turkey industry and lots of turkey litter (manure + bedding) to manage. The litter will be delivered to the Fibrominn plant in tightly covered trucks and unloaded in negative pressure buildings to prevent the escape of odors[82]. The furnace will operate at over 1500ºF, heating water in a boiler to produce steam. The steam drives a turbine and generator to produce electricity. Fibrowatt in the U.K. has converted more than three million tons of poultry litter to electricity (as of 2001).

Rahr Malting – Shakopee, Minnesota. Rahr Malting is a malting plant in Shakopee, MN that conducted a feasibility study of generating heat and electricity from biomass (primarily switchgrass)

---

[81] Fibrominn, Benson, Minnesota. http://www.fibrowattusa.com/US-Benson/index.html
[82] Fibrominn brochure, "Power from Poultry Litter," http://www.bensonmn.org/fibrominn/flyer.pdf

in 2001[83]. The total cost of the project was estimated at $32 million and included technologies for direct combustion and gasification.

By producing switchgrass in Minnesota on marginal land, the project estimated a necessary 3,000 to 5,000 acres of land could be located within 50 miles of the plant. The study used target prices for switchgrass delivered of $30 per ton and $40 per ton to determine economic feasibility.

The emission testing provides a great comparison of air quality parameters generated in a 20 MW power plant based on the source (Table 5.2). Biomass fuels were superior on SO_2, NO_x and CO_2[84].

Table 5.2 20 MW Power Plant Emissions Comparison (Modified from Rahr Malting)

Pollutant (tons/year)	Biomass Gasification[a]	Wood Direct Combustion[a]	Diesel Fired Turbine[b]	Natural Gas Turbine[b]	Coal Fired Plant[b]
SO2	>1	>1	41	38	377
NOx	275	140	1,487	357	549
Total VOC	1	13	67	20	6
PM10 (controlled)	22	55	47	34	14
CO	4	98	38	6	27
CO2	Zero net	Zero net	129,808	122,290	259,000

a Based on test data, scaled to 20 MW
b Based on USEPA AP-42 emissions factors scaled to 20 MW

5.2.4 Co-generation Power Plants The Department of Energy (DOE), The Tennessee Valley Authority (TVA), The Electric Power Research Institute (EPRI) and the electric utility industry have been looking at burning biomass with coal since 2000[85]. Co-firing biomass with coal requires special handling procedures of the coal. Northern Indiana Public Service Company (NIPSCO) has had two power plants involved in these co-firing tests, burning between 5-10 percent biomass (Table 5.3). DOE Co-generation priorities shifted to gasification in 2003, but these projects continued.

---

[83] Rahr Malting 20 Megawatt Biomass to Energy Project, Feasibility Study. 2001. http://www.me3.org/issues/biomass/rahrchpstudy.pdf

[84] SO2 is sulfur dioxide, NOx is nitrogen oxide, CO2 is carbon dioxide, CO is carbon monoxide, VOC is Volatile Organic Compounds and PM10 is particulate matter suspended in the atmosphere that will pass through a 10 micron filter.

[85] Paul Grabowski, "Biomass Cofiring," Technical Advisory Committee, US DOE, Energy Efficiency and Renewable Energy, Biomass Program. March 11, 2004. http://www.bioproducts-bioenergy.gov/pdfs/PGCofiring.pdf

Table 5.3 DOE Biomass and Coal Co-firing Research

Utility and Plant	Boiler Capacity	Biomass Heat Input (max)	Biomass Type	Average Moisture	Coal Type	Biofuel Feeding
TVA Allen	272 MW	10%	Sawdust	44%	Illinois basin, Utah bituminous	Blending biomass & coal
TVA Colbert	190 MW	1.5%	Sawdust	44%	Eastern bituminous	Blending biomass & coal
NYSEG Greenidge	108 MW	10%	Wood waste	30%	Eastern bituminous	Separate injection
GPU Seward	32 MW	10%	Sawdust	44%	Eastern bituminous	Separate injection
MG&E Blount St.	50 MW	10%	Switchgrass	10%	Midwest bituminous	Separate injection
NIPSCO Michigan City	*469 MW*	*6.50%*	*Urban wood waste*	*30%*	*PRB, Shoshone*	*Blending biomass & coal*
NIPSCO Bailly	*194 MW*	*5-10%*	*Wood*	*14%*	*Illinois, Shoshone*	*Blending (Trifire)*
Allegheny Willow Is.	188 MW	5-10%	Sawdust	tbd	Eastern Bituminous	Blending (Trifire)
Allegheny Allbright	150 MW	5-10%	Sawdust	tbd	Eastern Bituminous	Separate Injection

The research has shown that there is a slight decrease in efficiency by co-firing with biomass, but there are significant reductions in nitrogen oxides (NO_x), sulfur dioxide (SO_2), and carbon dioxide emissions (CO_2). These are similar air emission reductions as were found in the Rahr Malting feasibility study above.

The 2005 Indiana Renewable Energy Resources Study lists 9 power plants using from as little as 1.0 percent biomass to as much as 44 percent biomass with coal[86]. Other power plants have the capacity to burn multiple feedstocks. Another example is the power plant at the University of Iowa, Ames. They have developed a partnership with the Quaker Oats processing plant in Cedar Rapids, IA and receive oat hulls that they blend and burn with coal[87].

The 725 MW, Alliant Energy Chariton Valley power plant has been running tests examining the feasibility of co-firing switchgrass with coal since 2000[88]. Much of their work has been focused on developing an efficient system to move 1,000 pound, square bales of switchgrass from many

[86] 2005 Indiana Renewable Energy Resources Study. State Utility Forecasting Group, Purdue University, West Lafayette, Indiana. September 2005. engineering.purdue.edu/IE/Research/PEMRG/SUFG/PUBS/PUBS/2005_Renewables_Final.pdf
[87] Biomass Energy at the University of Iowa. http://www.facilities.uiowa.edu/uem/biomass/biomassindex.htm
[88] Bill Morton. "Co-firing a Power Plant with Switchgrass." BioCycle Renewable Energy Conference. Madison, WI. September 2005.

different fields into the power plant burner. As mentioned in the Biomass Feedstock Storage and Handling section, they have developed a system to off-load semi-trucks very rapidly. Their handling system also de-bales the twine, shreds and grinds the switchgrass and meters it into the burner. They have also been running emissions tests and monitoring slag buildup of the burner.

5.3 Gasification

Gasification is the liberation of volatile, gaseous compounds at high temperatures with the controlled restriction of oxygen. This creates a flammable producer gas ready to combust. One of the challenges with a gasifier is that this producer gas does not substitute directly for natural gas. In addition the composition of the gas varies with the feedstock entering the gasifier.

Gasifiers produce three products: heat, producer gas, and ash. To operate as an efficient system, beneficial uses need to be developed for all three products. Many processes require heat or drying. If the heat can not be used directly by the gasifier operators, there may be opportunities to market it to a nearby school or industry. The ash contains phosphorus and may be developed into a soil amendment or plant fertilizer.

The producer gas contains many valuable organic compounds. These can be used to produce power directly, or can be used to develop further refined fuels and products. It is important to understand that to fully utilize the gasifier producer gas for any kind of power generation, additional equipment is necessary.

5.3.1 Benefits and Liabilities of Gasification The U.S. DOE rates gasifiers as very good at converting the lignin (25-30% of the biomass) into useful products of the producer gas[89]. Lignin has an energy value, but it is often difficult to separate it from the simple sugars for efficient recovery. Gasification converts most biomass feedstocks into a clean producer/synthesis gas.

Another significant benefit is the low air emissions relative to coal. Data emissions that were conducted on a gasifier for the Rahr Malting plant in Minnesota were presented in Table 5.2. These showed significant reductions over coal and diesel fuel. In addition, research conducted in

[89] Large Scale Gasification. US Department of Energy (DOE)-Energy Efficiency and Renewable Energy. http://www.eere.energy.gov/biomass/large_scale_gasification.html

Texas found that mixing small amounts of beef feedlot manure (7-15%) with coal, reduced the nitrous oxide emissions levels with potential to reduce energy costs of delivering less coal to the power plant[90].

Other benefits of gasifiers are[91]:
- Reduction of waste volume by over 90%, reducing it down to ash content.
- Gasifiers generally have few moving parts.
- Gasifiers are built for specific application after testing response of feedstock in a test burn.
- There are heat and ash co-products, in addition to the energy-rich gas, that also have value.

The University of Minnesota has just recently purchased gasifiers to be installed at their Morris, UMN experiment station. The University will be feeding corn stover, corn earlage, wheat straw, soybean residue, native grasses and hybrid poplar[92]. In addition they plan to develop best management practices, templates for pricing structures and contracts and templates for environmental permitting[93]. Operation of the gasifiers will provide power to the University of Minnesota Morris facilities and allow research in biomass collection and storage.

The DOE goes on to list the technical barriers for gasification as[94]:

- Feed processing and handling – as mentioned in Section 5.1, handling and storage of all biomass feedstocks are a challenge. Maintaining consistent feedstock quantities and qualities are not easy. Various gasifiers feed some kinds of biomass materials in more easily than others, so switching biomass feedstocks may also have limitations.
- Producer/syngas cleanup and conditioning – the gaseous compounds leaving the gasifier do not meet standards for other more conventional fuels, like natural gas, and must be further treated or cleaned up to meet those standards. Cleanup and conditioning are required to remove tar, particulates, alkali, ammonia, chlorine, and sulfur. This challenge is further compounded by economic, and environmental performance standard criteria.
- The gas produced by gasifiers can not be stored. It must go directly into the next process.

---

[90] John M. Sweeten and Kalyan Annamalai, "Gasification & Combustion of Cattle Feedlot Manure," BioEconomy Conference, Iowa State University, Ames, IA August, 30 2005. http://www.valuechains.org/bewg/Conf2005/Presentations/John_Sweeten.pdf
[91] Modified from the BGP gasifier information at www.infectrol.com/tech_and_apps.html.
[92] AG INNOVATION NEWS, Ag. Utilization Research Inst. (AURI) Vol. 14, No. 3, Jul-Sept 2005. www.auri.org/news/ainjul05/energycenter.htm
[93] NRCS USDA Awards $12.6 million for biomass research and development www.nrcs.usda.gov/technical/grants.html
[94] Department of Energy (DOE), Energy Efficiency and Renewable Energy, Large-Scale Gasification, Technical Barriers for Gasification. http://www1.eere.energy.gov/biomass/large_scale_gasification.html

- System integration – as mentioned earlier it is important to integrate all feedstocks and products with existing enterprises and operation. Anything less that full utilization will not be efficient.
- Material design – there are often issues in dealing with abrasive ash and containment vessel, this includes development of sensors and analytical instruments necessary to optimize systems.

5.3.2 Gasifier Vendors Gasification has been conducted for many years and there are many vendors. Generally each company evolves around gasification of a specific material. Two gasifier venders that focus on biomass materials are Coaltec Energy USA Inc. and BGP, Inc.

Coaltec Energy USA, Inc

Coaltec Energy USA Inc. is the U.S. distributor for Westwood Energy Systems gasifiers (Figure 5.3, www.westfibre.com). They market 3 basic gasifier sizes although the technology can scale up or down to address a broad range of project requirements. The main component of these systems is a down-draft fixed-bed gasifier where gasification takes place in an oxygen-starved environment thus controlling NOx (nitrous oxide) formation. The low pressure system allows for gasification without carryover of particulate matter.

Figure 5.3 Westwood Energy Systems Gasifier, Westbank, B.C., Canada

The system is designed for ease of use with PLC controls, requiring limited operator interface. The gasifier needs minimal maintenance as it has no internal moving parts and uses rams for supplying the feedstock and ash removal. Carbon monoxide is the main product of the gasification along with some hydrogen and methane, quantities dependant on the feedstock. The syngas produced will vary in temperature between 1600-1800° F. The system can easily be modified to allow removal of all or a portion of the syngas prior to combustion, providing opportunities to use it for the production of hydrogen gas or liquid fuels.

Coaltec's gasification Demonstration and Testing Center, at Southern Illinois University's Coal Research Park, Carterville Illinois, is used to test new fuels and combinations of fuels at a commercial scale. Depending on the feedstock, it can consume up to two tons of fuel/hour, producing approximately 25 MMBTU/hr. and when coupled to a heat exchanger and turbine could generate approximately 1.5 MW of power. Coaltec plans to install a smaller demonstration gasifier with a Fisher-Tropsch synthesis process at their test facility in late 2006. Alternative fuels that have been successfully tested include cow manure, turkey litter, ethanol mash, cornstover, fine coal refuse, spent brewer's grain, and plastics.

The three sizes of gasifiers are measured in square feet of gasifier residence chamber footprint (96, 64, and 32 square foot models). Pricing is dependent on system requirements and fuel specs. Additional energy converters would increase the cost of a system. Prior to purchasing a gasifier, a test burn of the intended feedstock would need to be conducted in most cases to ensure efficient design of the new gasifier. The test burn costs about $70,000 - $100,000, depending on test protocol requirements.

It is impossible to eliminate all of the risks associated with new applications of proven technologies, however, the ability to test fuels and demonstrate their performance at a commercial scale minimizes risks. The demonstration facility has a significant amount of monitoring equipment to track the system's performance and emissions during testing.

Additional benefits include:

- Energy Cost Savings – As conventional energy supplies, such as natural gas, oil and power, rise in price the gasifier offers a solution that can provide great economic savings as well as self sufficiency on energy needs- and most of all – long term cost control.
- Waste Management – Any combustible material or blend of materials up to 60% moisture content can be processed as a fuel in the gasifier. A practical and economic alternative to sometimes costly waste disposal programs or in instances where regulatory requirements are stringent.

Barbara T. Gaume
Director of Marketing
Coaltec Energy USA, Inc.
Dallas Office
Phone: 214.542.3321
bgaume@sbcglobal.net

Coaltec Energy USA, Inc.
5749 Coal Drive
Carterville, IL 62918
(618) 453 – 7324, ext. 248

BGP, Inc.

BGP, Inc. is a Canadian company that manufactures and sells the Brookes Gasification Process (BGP) with an emphasis on destroying waste materials. The BGP gasifier operates between 850 – 1400° C (1,500 – 2,500° F), which is a bit hotter than the Coaltec USA, Inc gasifier.

BGP has a power unit that attaches to their gasifier to produce 0.9-1.2 MW of electricity. Ten gasifiers can be banked together to operate about 10 MW generator. With the modular approach one gasifier can be taken off line for servicing without disrupting production.

One of the selling points of the BGP system is total pathogen destruction. They have installed a demonstration gasifier at North Carolina State University (NCSU) Animal and Poultry Waste Management Center to test the destruction of waste and pathogens poultry mortalities, chicken litter, hog manure, processing plant wastes and other manures (Figure 5.4)[95].

[95] NC State Swine Extension News. "New Gasifier at NCSU," Volume 27, Number 3. http://www.infectrol.com/images/NCSUSwineArticleApril04.pdf

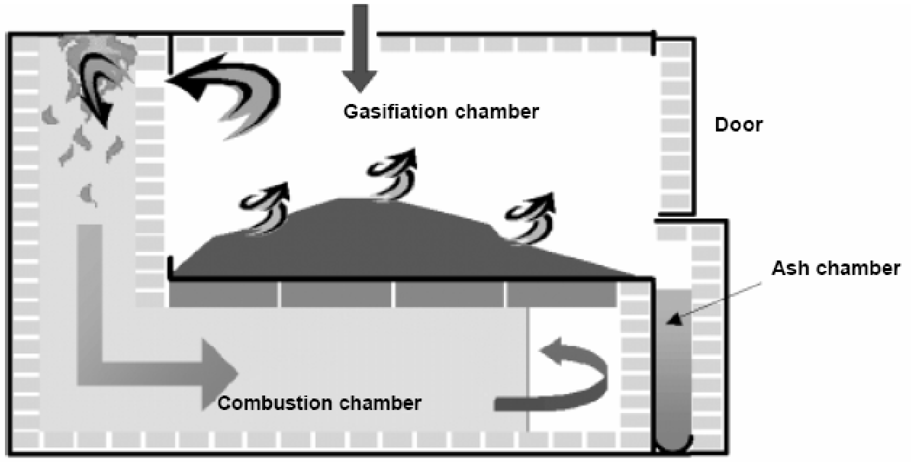

Figure 5.4 BGP Gasifier Operation at NCSU

"The BGP's can be used to treat other waste material such as: contraband drugs, sewage treatment sludge cake, manure, animal carcasses or offal, municipal waste, certain chemical wastes, hazardous materials and in certain cases municipal waste with segregation, rendering them totally safe and producing negligible emissions to air.[96]"

BGP, Inc.
Gary Ainlay
800.943.8287 office
garyd.ainlay@sympatico.ca
www.infectrol.com

Pyromex Waste to Energy

The Pyromex gasification system is designed to run exclusively on municipal sewage solids. The Pyromex technology runs at the highest temperatures of these three gasifier technologies (1,000° – 1,700° C). This technology which was established in Switzerland, could power a 1.2 MW generator on a gasifier that had a loading rate of 10 tons per day of sewage sludge.

PYROMEX AG
Schoengrund 1
6343 Rotkreuz/ Switzerland

Herb Teague
530-275-8062
herb@ils-partners.com

[96] BPG, Inc website. http://www.infectrol.com/index_about.html

5.4 Fast Pyrolysis Bio-Oils

Recalling the process of combustion from Section 4.2.2 Burning Biomass, pyrolysis is the step in the combustion process that occurs after the drying process. It occurs at lower temperatures than gasification (400-600° C or 750-1,100° F)[97]. Volatile carbon-based materials are turned into a gaseous state and liberated from the remaining char. Once the gaseous organic materials leave the reaction chamber, they are condensed into a liquid, pyrolytic bio-oil (Figure 5.5).

When the feedstock is dried to less than 10 percent moisture, pyrolytic bio-oil will yield 60 – 75 percent with about 13 – 25 percent resulting in char. Assuming a conversion of 72 percent of the biomass feedstock to liquid by weight, pyrolytic bio-oil will yield about 148 U.S. gallons per ton[98]. Fast Pyrolysis is an energy intensive process, but recycled combustible gases can supply about 75 percent of the required energy.

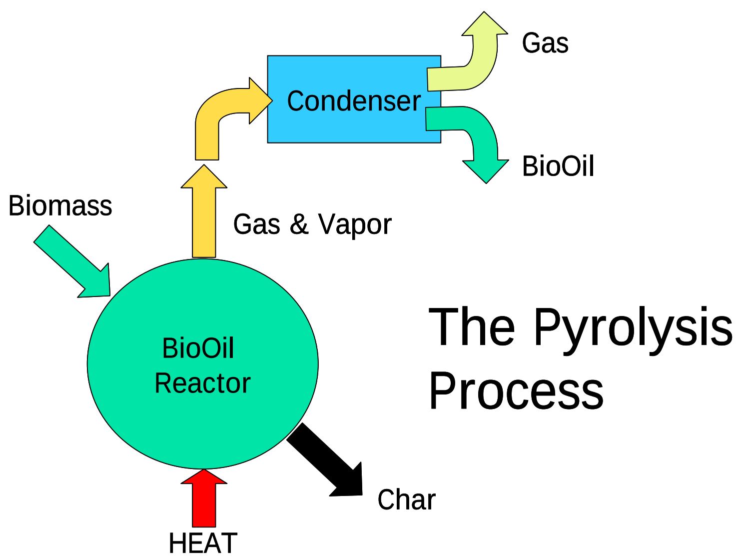

Figure 5.5 The Pyrolysis Process (Renewable Oil International)

Fast Pyrolysis is a technology that is in the initial stages of commercialization. A fairly current summary of North American commercial-scale fast pyrolysis plants is provided in the Wisconsin BioRefining Development Initiative, Fast Pyrolysis document referenced above:

- Ensyn announced in 2003, construction of a CN$9 million biorefinery in Renfrew, Ontario. This facility would employ 16 people and process 60 tons of dry feedstock/day.

[97] Brown, Robert, Biorenewable Resources: Engineering New Products from Agriculture. Iowa State Press. Ames, IA 2003.
[98] "Fast Pyrolysis," BioRefining Process. Wisconsin BioRefining Development Inintiative. http://www.wisbiorefine.org/proc/fastpyro.pdf

- Between 1989 and 2003, the Ensyn Company had 6 plants operating which were reported to produce 5 million gallons of bio-oil per year.
- The Dynomotive Corporation has recently reached the commercialization stage.
- The Biomass Technology Group (BTG) BV is involved in the engineering of a 50 ton per day fast pyrolysis plant that would use clean wood residues as a feedstock.

5.4.1 Benefits and Liabilities The benefits of fast pyrolysis, bio-oil are similar to gasification. This technology reduces the volume of the feedstock significantly. Fast pyrolysis is unique from the perspective that it can be condensed at the feedstock production site and then transported more cost-effectively to another central facility for further-processing. Bio-oil is appealing because it produces a liquid fuel. There are significant environmental benefits regarding air emissions and waste reduction.

The liabilities are related to the fledgling level of commercialization that this technology faces. The bio-oil is similar to heating oil, but differs in character depending on the biomass feedstock used. Like the gasification, producer gas, fast pyrolysis bio-oil is not directly usable in many applications. It can be cleaned and used in conventional liquid fuels. Because there are only a handful of commercial fast pyrolysis plants, there is less confidence and understanding of the technology and economic commitments necessary to operate a fast pyrolysis plant.

5.4.2 Fast Pyrolysis Venders Three venders are presented here. Two of them are commercial companies mentioned above: Ensyn Company and DynaMotive, both Canadian-based companies. The third vender is a U.S. company, still in the demonstration-scale operation, Renewable Oil International, LLC, headquartered in Alabama.

Renewable Oil International, LLC

Renewable Oil International, LLC was formed in 2001 and received notoriety in 2003 with the operation of a 5-ton of biomass per day fast pyrolysis pilot plant on a Russellville, Alabama poultry farm (Figure 5.6). This 5 ton plant converted broiler litter into bio-oil.

Figure 5.6 Renewable Oil International, LLC, 5-ton/day pilot plant in Russelville, AL

Phillip Badger, President of Renewable Oil International, is ready to move his company to plant that would process 15 tons per day of dry biomass. This would produce about 2,000 gallons per day of bio-oil. The process works best with dry, ground feedstocks like corn stalks. Since the pyrolysis process is heat intensive, the heat might provide the energy to dry manure solids or compost down to 10 percent.

The bio-oil could be used to run a diesel generator. The size generator that is appropriate for a 15-ton per day fast pyrolysis plant would be 100 kW turbine. So electricity could be generated from the bio-oil.

Phillip C. Badger, President & Chief Manager, Renewable Oil International, LLC
3115 Northington Court
P.O. Box 26
Florence, AL 35630
Phone (256) 740-5634
Fax (256) 740-5635
Email pbadger@renewableoil.com

Ensyn Corporation

The Ensyn Corporation has developed the Rapid Thermal Processing or (RTP™). They have the most commercial capacity operational today. Their largest plant, in Renfrew Ontario, processes 60 dry tons of biomass per day. In addition they have six other smaller plants that produce collectively, 5 million gallons a year. (www.ensyn.com)

Ensyn Renewables Inc.
400 W 9th Street
Willmington, Delaware
Phone: (302) 425-3740
Fax: (302) 425-3742

DynaMotive Energy Systems Corporation

As of Spring of 2005 DynaMotive was ramping up its first commercial fast pyrolysis plant in West Lorne, Ontario. This plant has a 100 ton per day processing capacity.

DynaMotive Corporation
James Acheson, Chief Operating Officer (U.S.)
134 North Van Ness Avenue
Los Angeles, CA 90004
Phone: (323) 460-4900
Fax: (323) 465-2617

5.5 Anaerobic Digestion

Anaerobic digestion is the cultivation of methagenic bacteria in the absence of oxygen. Manure methane digesters are very complex microbiological ecosystems. The efficiency of conversion of manure to methane gas depends on many factors like quality of manure entering the digesters, intensity of digester management (retention time of manure in digester, temperature of the digester and whether it is continuously loaded or not), and also the species of livestock. As the management intensity of the conversion efficiency is increased, the possibilities of the digester system being upset also increase.

While digesters can be complex, there is some stability in the buffering nature of the digester's biological ecosystem. Natural buffers will compensate for small fluctuations in the chemical nature of the liquid material within the digester. A brief overview of digester processes and function are described below.

5.5.1 The Anaerobic Digestion Process Anaerobic digesters are similar to the rumen (digestive system) of cows. In fact, a great deal of manure digester microbiology evolved from research conducted by ruminant physiologists. When a cow eats plant material, it gets broken down into smaller molecular units (sugars starches and fibers) by physical, biological and chemical processes.

In a digester, the same thing happens. Here the manure that enters the digester contains partially digested plant parts (Figure 5.7). Acid forming bacteria feed on these carbohydrates and produce volatile organic acids. These acids are what the methane-forming bacterial eat. As these methagenic bacteria respire, they release methane. While this is described here as a linear process, all these steps are happening at the same time.

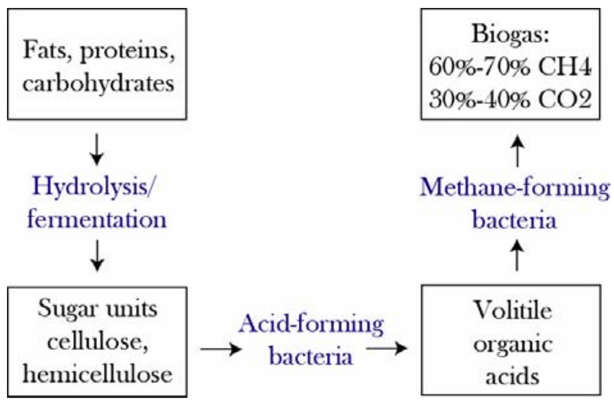

Figure 5.7 Microbiology of an Anaerobic Digester

Operating temperature - The descriptive temperature ranges with which digesters operate are: psychrophilic (less than 68^{o} F), mesophilic (95^{o} to 105^{o} F) and thermophylic (125^{o} to 135^{o} F)[99]. The psychrophilic digesters are not heated. Mesophilic digesters are heated to about 100 degrees. The thermophilic digesters are heated even more. They are the most efficient, but also the most sensitive to shocks within the digester system. Anaerobic lagoons (outside earthen containers) are also digesters. The operating temperatures of these earthen, anaerobic lagoons fluctuate with the season. They will warm up in the summer, and during the winter methane production is reduced.

Digester structure - The least management-intensive digester is an anaerobic lagoon. These digesters were very popular in the 1980's and 1990's because they did not require much

[99] Joseph Kramer, Agricultural Biogas Casebook – 2004 Update. Resource Strategies, Inc. http://www.mrec.org/pubs/AgriculturalBiogasCasebook2004Update.pdf

maintenance. Innovations in lagoon technology have added liners in the bottoms and covers on the top to collect the methane. These covers are relatively inexpensive, but the yield of methane gas is also the lowest for covered earthen lagoons.

There are in-ground concrete digesters and above-ground tank digesters. Insulation and heating needs become decision-making factors. Plug-flow digesters have a new batch of manure added as an equivalent volume of liquid is pushed out of the digester at the other end. Mixed digesters are agitated. Theoretically thermophilic, mixed digesters keep all the bacteria growing and digesting most efficiently. Costs increase as digesters operate at higher temperatures and get mixed. The yield of methane gas also increases with management intensity.

Manure Quality – The criteria used for loading an anaerobic digester is volatile solids. These are the organic portion of the total solids. Two factors weaken the concentration volatile solids in manure. The first factor is the addition of water. A certain amount of water is necessary to get the appropriate loading rate (manure digesters are designed for liquid manure). If too much water is added the concentration of volatile solids will be less than optimal.

The second factor that weakens the concentration of volatile solids is time. The longer the duration of time between when feces are produced until they are utilized, the more degraded the volatile solids will be. So if manure sits in a pit for 4-5 months before it is utilized, some of the methane-producing potential will be lost. To get the most energy out of manure it must be utilized when it is produced.

A University of Missouri Extension bulletin below provides some interesting comparisons between species and energy requirements (Tables 5.4 & 5.5)[100]. At the University of Missouri, the early research on methane production from manure was based on their work with mesophilic, mixed digesters. Currently, the hogs in White County are produced over pits where the manure is stored for 5-6 months between cleanouts. Digesters operating on pit manure will yield less than these values.

[100] Charles D. Fulhage, Dennis Sievers and James R. Fischer. Generating Methane from Manure. University of Missouri Extension. G1881. http://muextension.missouri.edu/explore/agguides/agengin/g01881.htm

Table 5.4 Potential Gas Production of Swine, Dairy, Poultry and Beef (University of Missouri)

	Swine (150 lbs)	Dairy (1,200 lbs)	Poultry (4 lb bird)	Beef (1,000 lbs)
Gas yield, cu. ft. per lb. volatile solids destroyed	12	7.7	8.6	15
Volatile solids voided, lb./day	0.7	9.5	0.044	5
Percent reduction of volatile solids	49	31	56	41
Potential gas production cu. ft. per animal unit/day	4.1	22.7	0.21	31
Energy production rate, Btu/hr/animal	103	568	5.25	775
Available energy Btu/hr (after heating digester)	70	380	3.5	520

Table 5.5 Some Energy Requirements and Animals Needed to Meet Them (Univ. of Missouri)

	Heat required (Btu/hr)	Swine (150 lbs)	Dairy (1,200 lbs)	Poultry (4 lb bird)	Beef (1,000 lbs)
Kitchen range(1)	65,000	77	14	1,547	11
Water heater(2)	45,000	107	20	2,143	15
Refrigerator(3)	3,000	22	4	429	3
Heat 1,500 sq. ft. home(4)	37,500	535	99	10,714	72
In-bin grain drying heater(5)	2,000,000	14,285	2,631	285,714	1,923
50 hp tractor with full load(6)	637,000	4,550	838	91,000	612

(1) Assumed to operate 2 hrs/day, i.e., 24-hr average of 5,417 Btu/hr
(2)Assumed to operate 4 hrs/day, 24-hr average = 7,500 Btu/hr
(3) Assumed to operate 12 hrs/day, 24-hr average = 1,500 Btu/hr
(4) Assumed 25 Btu/hr/sq. ft. heat requirement
(5) Assumed to operate 12 hrs/day during drying season, 24-hr average = 1 million Btu/hr
(6) Assumed to operate 12 hrs/day, 24-hr average = 318,500 Btu/hr

A similar table, Table 5.6, was produced by Mark Moser of RCM Digesters, based on dozens of digesters he has designed and built in the U.S. and around the world[101]. These comparisons show that a finishing house with 4,400 hogs could power a 40 kW continuous output generator.

Table 5.6 Biogas Production Potential (RCM Digesters)

	kWh/ head/day	Biogas Production ft3/d	Population for 40 kW continuous output generator
Cow	2.5-3.7	65-80	400
Sow	0.2 - 0.3	5-7.5	3,200
Nursery	0.06 - .09	1.4 –2.1	11,000
Finisher	0.15 – 0.22	3.5-5.5	4,400
Beef Feeder	1.8 – 2.2	45 - 55	600
Laying hen	.01	0.25	72,000

[101] Mark Moser, "Farm Digesters and Anaerobic Digestion – 101." RCM Digesters, Inc. www.rcmdigesters.com

Manure Byproducts - Just as important as producing methane, or electricity from methane, is utilizing all the things that go along with using the carbon and hydrogen from the methane. The effluent coming out of a digester has fiber in it. Some of the energy is still in it, and the nitrogen and phosphorus in the manure are in a more available form than they are in fresh manure. GHD, Inc., another anaerobic digester builder, has an excellent flow diagram of materials through a manure digester system (Figure 5.8)[102].

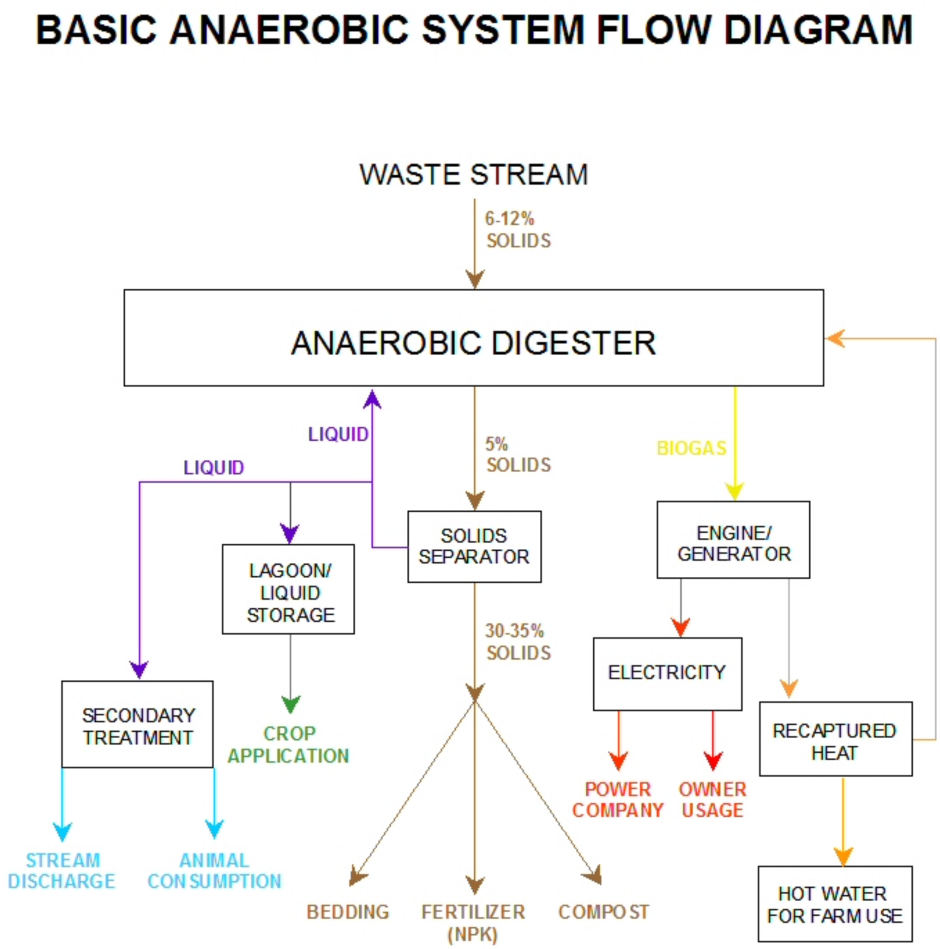

Figure 5.8 Anaerobic Digester Materials Flow (GHD, Inc.)

5.5.2 Benefits and Liabilities Anaerobic digesters have many benefits.

- Heat and Electricity production
- Fly and Odor control
- Weed seed and pathogen reduction
- Enhanced manure nutrient availability
- Carbon-credit revenue

[102] GHD, Inc, Anaerobic Digesters. www.ghdinc.net

The list of anaerobic digester liabilities is equally as exciting.

- They haven't always worked. All the vendors listed below are using technologies that have track records of success. But the hard reality is that in the last 20 years a lot of digesters that have been built are no longer running. There are legitimate reasons for this. One good reason is that we know a lot more about building and running digesters than we used to.
- Revenue from the sale of methane-generated electricity may not provide any economic security. It is difficult to obtain a good price for electricity generated on the farm. There are also often interconnection costs. Sometimes the cost of being connected to the grid costs as much as the revenue from electricity sales. New policies are being developed, and things are changing, slowly.
- The methane gas generated from a manure-digester can not be stored. It has to be used as it is produced or flared off into the atmosphere.
- It is less costly and more efficient to build a digester that is designed from the ground up as an integrated component of the livestock operation and buildings.
- It is difficult to just 'try it out' for a while. Once you make the commitment to build and operate a digester, it is a long term decision.

5.5.3 Anaerobic Digester Vendors Digester construction and operation is a commercial industry. While the exact count of operating farm-scale digesters is always changing, there are between 50-100 manure digesters operating or being planned in the U.S. These vendors all bring creativity and experience to the digester market place. The three seasoned vendors are GHD, Inc., RCM Digesters, and Microgy. A fourth digester technology that is worthy of an honorable mention is the ORBIT digester system.

GHD, Inc.

GHD, Inc. is a successful newcomer to the anaerobic digester market. They have built two digesters in Jasper County, Indiana and are currently building a third. The Herrema Dairy is one of the digesters showcased on their website, www.ghdinc.net.

The Herrema Dairy is a 3,500 cow dairy that is generating 600 kW hours of electricity. The waste heat is used to heat the digester, dry digester solids and heat the dairy (Figure 5.9). They are using the dried solids as bedding. The GHD, Inc. digesters are very successful. While the GHD focus has been on dairy manure digesters, they have built digesters for other species. They are looking for a swine manure project with which to expand their digester technology.

Figure 5.9 GHD, Inc. Water tank and Digest Equipment Bldg. Herrema Dairy - Fair Oaks, IN

GHD, Inc.
Steve Dvorak
P.O. Box 69
Chilton, WI 53014
Phone: (920) 849-9797
Fax: (920) 849-9160
ddghd@tds.net
www.ghdinc.net

RCM Digesters

Mark Moser has built over 40 anaerobic digester systems since 1982. RCM Digesters exist for all the major species and across a variety of design platforms. RCM digesters has experience with single feedstock digests (only one kind of manure), multi-waste digesters, and multi-farm digesters.

A recent RCM Digester project is at the Kuthe Farm in Nebraska. Based on the manure from 8,000 finishing hogs, enough methane is produced to power the 85 kW generator pictured in Figure 5.10.

Figure 5.10 The 85 kW Generator at Kuthe Farm in Nebraska, RCM Digesters

RCM Digesters
Mark Moser
P.O. Box 4716
Berkeley, CA 94704
Phone: (510) 834-4568
Fax; (510) 834-4529
www.rcmdigesters.com

Microgy Cogeneration Systems, Inc.

Microgy Cogeneration Systems, Inc. designs and builds the highly efficient, thermophilic, mixed digesters. They have built several digesters in the U.S., but the technology came from Europe, where several dozen digesters are running. The innovative aspects of the Microgy digester system are that they install a very efficient digester, and they also operate it as part of the agreement. Microgy, Inc. even offers a program where they will build a Microgy-owned digester, completely eliminating the financing component for the farmer. They offer a turn-key digester system that does not draw time and energy away from a farm operator's livestock management needs (Figure 5.11). Because of the high digestion efficiency Microgy digesters are able to combine other organic feedstocks (co-digestion).

Figure 5.11 Microgy Anaerobic Digester Systems

Microgy Cogeneration Systems, Inc.
Mike Casper,
Phone: (847) 599-9248
www.environmentalpower.com/companies/microgy

Organic Biotechnologies, LLC (ORBIT)

This technology is currently in the testing stages. NCSU analyzed the performance of this high solids, thermophilic, modular digestion technology[103]. All three of those descriptors make it a technology to watch. Modular, skid-type technologies can facilitate the use of high capital, intensively managed digesters, on a small scale. This might have BioTown, USA applications in blending multiple municipal and farm wastes as a single feedstock.

5.6 Fermentation

The conversion of corn into ethanol by fermentation is one of the bright stars of the biomass renewable fuels industry. There are nearly 100 existing ethanol plants currently listed on the Renewable Fuels Association (RFA) website with expansion or new construction planned at 40 more facilities[104]. Ethanol prices the last 6 months have been high (Figure 5.12)[105]. Liquid fuel prices are high and the demand for renewable fuel oxygenates (MTBE replacement) will keep

[103] ORBIT digester at NCSU http://www.cals.ncsu.edu/waste_mgt/smithfield_projects/orbit/orbit.htm
[104] Renewable Fuels Association http://www.ethanolrfa.org/industry/locations/
[105] California Energy Commission http://www.energy.ca.gov/gasoline/graphs/ethanol_18-month.html

ethanol prices high. Ethanol fermentation/distillation from corn is a proven and profitable technology.

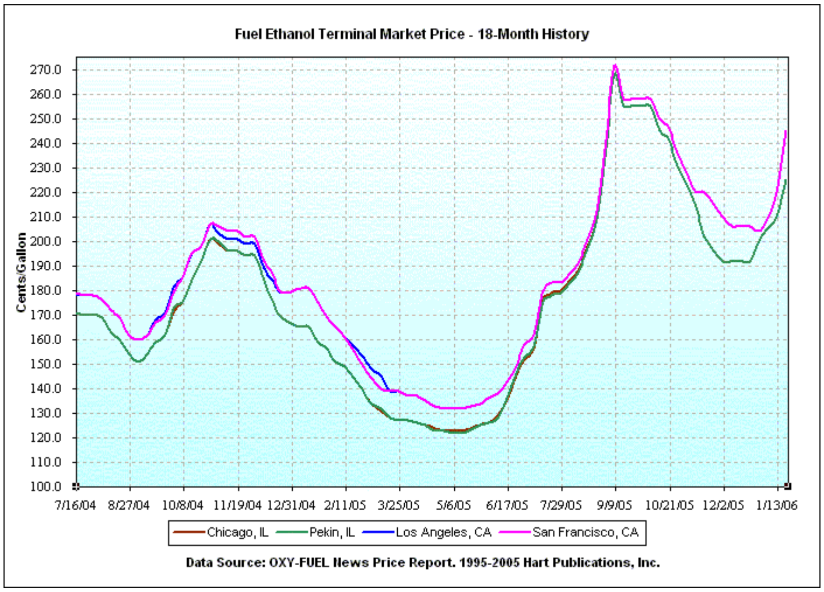

Figure 5.12 Fuel Ethanol Terminal Market Prices in Illinois and California

Currently there is only one, 102 million gallon per year, ethanol plant in South Bend Indiana that is operational (RFA website). Other ethanol plants have begun construction or announced plans to build they are:

- The Central Indiana Ethanol, LLC, in Marion with annual capacity of 40 million gallons,
- ASAlliances Biofuels, LLC, in Linden with an annual capacity of 100 million gallons,
- Iroquois Bio-Energy Company, LLC, in Rensselaer with an annual capacity of 40 million gallons,
- The Andersons Inc., in Clymers with an annual capacity of 100 million gallons, and,
- The Maize AgriProducts Inc. in Fowler with an annual capacity of 50 million gallons.
- Rush Renewable Energy in Rushville with an annual operating capacity of 60 million gallons.

When these proposed projects come on-line they will provide an additional 390 million gallons of Indiana ethanol annually.

5.6.1 Ethanol Fermentation Process (Corn) The ethanol industry has successfully commercialized the dry-mill process of converting a bushel of corn into ethanol (2.5-2.6 gallons/bu.), dried distillers grains and solubles (17 lbs DDGS/bu.) and carbon dioxide (16 lbs. CO_2/bu.)[106]. The dry-mill process is more specialized than the other commercial ethanol process, the wet-mill process. The wet-mill process produces other valuable co-products, such as high fructose corn syrup and gluten, but is also far more costly to build. Another emerging ethanol process is dry fractionation. Experimentally, this process increases the value of non-starch components before fermentation and greatly reduces the quantity of distiller's grains after fermentation. Current construction of commercial ethanol facilities are dry mill plants. Therefore, the discussion here is limited to the dry-mill process (Figure 5.13).

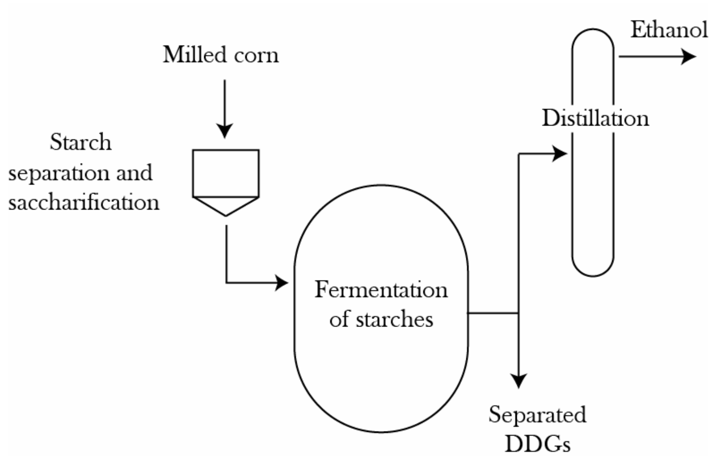

Figure 5.13 Schematic of Dry-Mill Ethanol Plant (modified from Brown)

Current Indiana Ethanol plants that are operating or have announced plans for construction are listed in Table 5.7. When these plants are complete, they will have committed to using 197 million bushels of corn. These seven plants will produce 492 million gallons of ethanol, 1.6 million tons of DDGS, and nearly 1.54 million tons of CO_2. It should be noted that only the South Bend plant is currently operational. Proposed plants must still get through the permitting and construction phase. The recently announced Fowler plant is still selecting a site.

DDGS have value as a feed ingredient, but require marketing and management to keep the high volume of DDGS from becoming a liability to the ethanol facility. DDGS have a high protein content (25-29%) and can be feed to livestock in small quantities. Feeding DDGS increases the

[106] Brown, Robert, Biorenewable Resources: Engineering New Products from Agriculture. Iowa State Press. Ames, IA 2003.

excretion of nutrients in beef, dairy and swine. Feeding DDGS in swine rations above 20% of ration, can create softening of pork[107].

Table 5.7 Indiana Dry-mill Ethanol Plants – Annual Inputs and Outputs

		Corn Mil Bu	Ethanol Mil Gal	DDGS Tons	CO2 Tons
New Energy Corp.	South Bend, IN	41	102	333,000	321,000
Central Indiana Ethanol, LLC	Marion, IN	16	40	130,000	125,000
ASAlliances Biofuels, LLC	Linden, IN	40	100	325,000	314,000
Iroquois Bio-Energy Company, LLC	Rensselaer, IN	16	40	130,000	125,000
The Andersons Inc.	Clymers, IN	40	100	325,000	314,000
Maize AgriProducts	Fowler, IN	20	50	162,000	157,000
Rush Renewable Energy	Rushville, IN	24	60	195,000	188,400
		197	492	1,600,000	1,544,400

DDGS also have potential for development as another biomass energy feedstock. Vance Morey has examined the potential for pelleting DDGS as a dry fuel for generating heat and power[108]. This energy use of DDGS is still at the experimental stage.

5.6.2 Ethanol Fermentation Process (Cellulose/Fiber). This technology is not at the commercial scale at this time. Iogen, Canadian-based Company, announced in January of 2006 that they are working with Royal Dutch Shell to build the first industrial scale cellulosic ethanol plant in Germany[109]. Others continue to encourage the construction of a commercial scale plant in the U.S. The process for making ethanol from celluosic fibers is similar to the process of making ethanol from corn (Figure 5.14). The difference is a pre-treatment process that reduces the fibers to sugars.

[107] Bob Thaler. Use of Distillers Dried Grains With Solubles (DDGS) in Swine Diets. South Dakota State University, Bookings. Extension Bulletin, ExEx 2035. August 2002. www.ddgs.umn.edu/articles-swine/ExEx2035.pdf
"soft pork" is a condition where the fat contained in pork meat is not solid at room temperature. From a marketing standpoint, soft pork is very undesirable.

[108] Vance Morey. Renewable Energy Research. Midwest Rural Energy Council. http://www.mrec.org/confer/2005_RenewableEnergy_Morey.pdf

[109] John J. Fialka and Jeffrey Ball. "Addiction Treatment." Wall Street Journal. Feb. 2, 2006. http://www.iogen.ca/news_events/iogen_news/2006_02_02_addiction_treatment.pdf

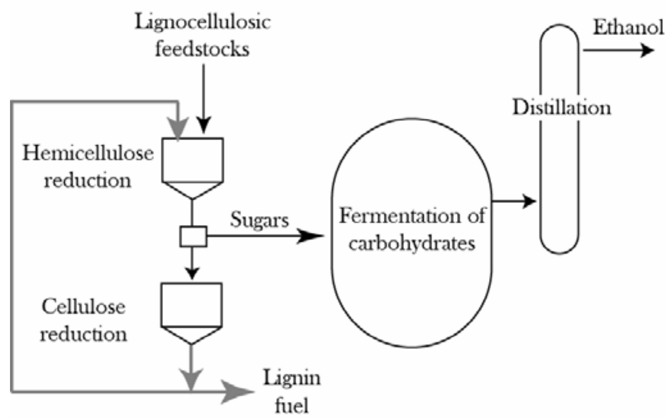

Figure 5.14 Schematic of Cellulosic Ethanol Plant (modified from Brown)

5.6.3 Benefits and Liabilities of Conversion of BioTown Corn and Fiber to Ethanol

Benefits:

- Dry-mill Ethanol Conversion is a proven and profitable technology investment with nearly 100 plants operating or under construction.
- Advances to the dry-mill ethanol conversion process continue to improve energy efficiency and co-product value.
- Demand for ethanol continues to increase more rapidly than the supply due to an increased demand for MTBE oxygenate replacements and increasing pressures on oil supplies (wars and hurricanes).
- White County, Indiana produces enough corn (20 million bushels) to support a 50 million gallon per year ethanol plant.

Liabilities:

- Ethanol plants are energy intensive. As conventional energy prices rise, the cost of producing ethanol also increases. This will be reduced as ethanol power shifts to biomass energy sources.
- DDGS markets are not automatic. Transportation and demand for DDGS must be managed. A 50 million gallon per year ethanol plant produces 162,000 tons of DDGS per year. It can not completely replace corn in feed rations and increases nutrient excretion rates in manure.
- Corn supplies may reach an economic limit. In 2004, Indiana harvested 929 million bushels of corn[110]. Upon completion, the seven plants in Table 5.7 will account for 197 million bushels -- or 21 percent of 2004 Indiana corn production. Three of the 'planned' plants in Table 5.7 are in counties that adjoin White County: Benton, Cass and Jasper Counties.

[110] USDA-National Agriculture Statistics Service (NASS) – Indiana 2004 Overview
http://www.nass.usda.gov/Statistics_by_State/Ag_Overview/AgOverview_IN.pdf

5.6.4 Ethanol Plant Vendors

Fagen, Inc.

The ethanol facility construction giant is Fagen, Inc. of Minnesota. Their website lists 45 ethanol projects related to either construction or expansion. That is nearly half of the existing 95, or so, known ethanol facilities.

Fagen, Inc.
P.O. Box 159
501 West Highway 212
Granite Falls, MN 56241
Phone: 320.564.3324
Fax: 320.564.3278

The Broin Companies

The Broin Companies have designed and constructed 21 operating ethanol plants, with seven currently under construction or development. The company has built plants in five states and manages, produces, and markets more than 700 million gallons of ethanol annually (www.broin.com).

The Broin Companies
2209 East 57th St. N.
Sioux Falls, SD 57104
Phone: (605) 965-2200
Fax: (605) 965-2203

For future reference, BioTown, USA needs to watch the progress of Iogen Corporation of Canada. They are the first fiber-to-ethanol (cellulosic) technology vender to discuss building a commercial scale cellulosic ethanol plant.

Iogen Corporation Headquarters (www.iogen.ca)
8 Colonnade Rd.
Ottawa, Ontario
Canada K2E 7M6
Phone: 613-733-9830
Fax: 613-733-0781

5.7 Transesterification of Vegetable Oil (Biodiesel)

The National Biodiesel Board (NBB) estimates there is currently the capacity for producing 354 million gallons per year in the U.S.[111] Thirty-five companies have announced plans to build biodiesel plants in the next 18 months. That will increase U.S. capacity by 278 million gallons of biodiesel fuel. The NBB points out that capacity is not the same as actual annual production. Biodiesel plants will operate at full capacity only when the demand for biodiesel is high enough.

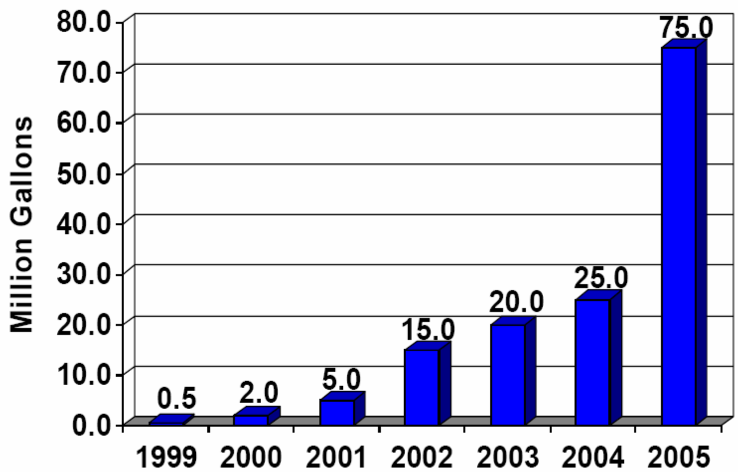

Figure 5.15 US Biodiesel Production Capacity Growth (NBB)

5.7.1 The Biodiesel Process - The conversion of vegetable oil to biodiesel is not a complicated process. It is a relatively simple chemical reaction that results in nearly a complete conversion of vegetable oil to biodiesel fuel. About 10 percent of the material leaving the process is glycerin Figure 5.16). Glycerin has market value but like the DDGS of ethanol, the quantities produced through the biodiesel conversion process are large enough to create marketing challenges.

The National Biodiesel Board (NBB) describes the primary commercial transesterification process as[112]:

> *"A fat or oil is reacted with an alcohol, like methanol, in the presence of a catalyst to produce glycerin and methyl esters or biodiesel. The methanol quickens the conversion process and is recovered for reuse. The catalyst is usually sodium or potassium hydroxide which has already been mixed with the methanol."*

[111] National Biodiesel Board. "U.S. Biodiesel Production Capacity." January 20, 2006. http://www.biodiesel.org/pdf_files/fuelfactsheets/Production_Capacity.pdf

[112] Biodiesel Production. National Biodiesel Board. http://www.biodiesel.org/pdf_files/fuelfactsheets/Production.PDF

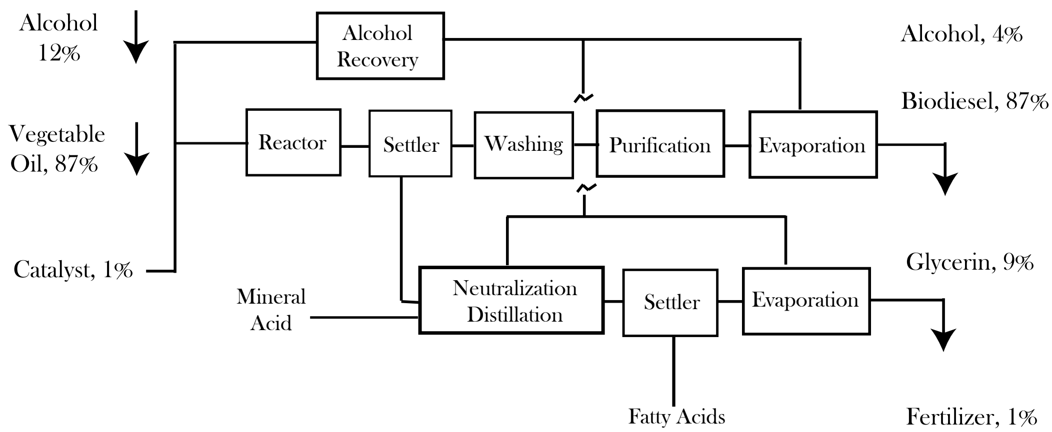

Figure 5.16 Process Flow Schematic of Vegetable Oil Conversion to Biodiesel (NBB)

5.7.2 Virgin Vegetable Oil as a Feedstock - Commercial biodiesel plants begin with vegetable oil as a feedstock, not soybeans. This is different from the conversion of corn to ethanol, where corn is delivered to the ethanol plant. Soybeans contain about 18.5 percent oil which is separated from the high-valued protein soybean meal[113]. A 60 pound bushel of beans yields about 11 pounds of oil and 48 pounds of meal[114].

To separate the oil from the meal, beans are crushed/extruded at a soybean crushing plant. This is not a significant challenge. It is just another step in the delivery and conversion of soybeans to biodiesel fuel.

As described in Chapter 3, Biomass Feedstocks, the 117,700 acres of White County soybeans, producing 63 gallons per acre of biodiesel fuel, would generate 7.4 million gallons of biodiesel fuel. This would also generate 6.3 million pounds of glycerin.

While soybean oil is the most common source of vegetable oil in the U.S., Canola and rapeseed oil are common feedstocks for biodiesel fuel in Canada and Europe. There may be some potential for growing spring canola in White County. It does not produce the same quantity of protein meal, but does produce 50 percent more oil per acre than soybeans.

[113] Dirk E. Maier, Jason Reising, Jenni L. Briggs, Kelly M. Day & Ellsworth P. Christmas. "High Value Soybean Composition." Grain Quality Task Force. Fact Sheet #39. Purdue University. November 23, 1998. http://www.ces.purdue.edu/extmedia/GQ/GQ-39.html

[114] The standard test weight of soybeans is 60 pounds at 13% moisture, while the standard test weight of corn is 56 pounds at 15.5% moisture.

The greatest advantage of using virgin vegetable oil in the biodiesel conversion process is cost associated with feedstock variability. Because the oil quality of fresh vegetable oil is relatively consistent, biodiesel plants can move large quantities of consistent oil through large facilities. The more specialized a facility is, the lower the costs of the processing operation. The trade off is that the fresh vegetable oil has many other uses and is more costly.

5.7.3 Used Vegetable Oil and Animal Fat as Feedstocks - While using virgin vegetable oil as a feedstock into biodiesel production has many benefits, it is not the only source of biodiesel feedstocks. Used vegetable oils, animal fats, Number 2 Yellow Grease and Brown Grease from restaurant grease traps, can all be converted into biodiesel fuel. These used materials are extremely variable and may not make the near-100 percent conversion to biodiesel fuel like that fresh vegetable oil. The economic trade-off with used oil and fat is that it is considered waste material and suppliers (used-oil generators) pay to have it collected.

Increasing energy prices and the added benefit of recycling a waste product are driving the commercialization of used oil feedstocks in the production of biodiesel fuels. One of the leaders in establishing a business model and developing a used oil technology is Piedmont Biofuels of Pittsfield, North Carolina[115]. They are a multi-service cooperative that not only offers biodiesel fuel from used oils, they offer education and training opportunities in setting up a facility. Piedmont Biofuels has been composting the glycerin.

White County and the BioTown, USA area have a significant supply of used oil, fat and grease. Within a 25-mile radius of Reynolds, there are 354 reported restaurants, most of which generate used vegetable oil (Table 3.3). Steve Godlove reports about 390,000 gallons of Brown Grease were cleaned out from restaurant grease traps in 2005 in the White County area[116]. Furthermore, Purdue University has pioneered the use of modified soybean oil for use in heating oil. Heating oil standards are not as stringent as the motor vehicle fuel standards and may be an excellent market for the used oil materials.

[115] Piedmont Biofuels. http://www.biofuels.coop/
[116] Steve Godlove, General Manager, Godlove Enterprises, Inc. Personal communication. December 2005.

5.7.4 Benefits and Liabilities of Conversion of Vegetable Oils and Animal Fats to Biodiesel Fuel

Benefits

- The conversion of oil and fat to biodiesel is a proven and profitable technology investment with nearly over 50 plants operating and another 35 under construction.
- Biodiesel conversion is a relatively simple and very compatible with conventional diesel fuel.
- As diesel fuel price increases, the economics of bioconversion of biodiesel fuel also improve.
- Engines burning biodiesel emit no sulfur dioxide, and less carbon monoxide, hydrocarbons and particulates. Biodiesel also adds lubricity.
- Recycling used vegetable oil and animal fat, especially Brown Grease from restaurants reduces environmental pressures from disposal of organic wastes.
- There are ample supplies of soybeans in White County, as well as sources of used vegetable oil and Brown Grease.

Liabilities

- Vegetable oil is very valuable already. Converting millions of gallons of vegetable oil into biodiesel fuel will raise the price of vegetable oil for all uses.
- Marketing or disposal of the co-product glycerin is not automatic, but markets exist if the glycerin is managed well.
- Burning biodiesel in engines has been reported to increase the nitrogen oxide levels slightly. Recent work by Bob McCormick of the National Renewable Energy Laboratory indicates that the influence on nitrogen oxide levels may be lower than previously reported. Engine design and emission test method impact the effect of biodiesel nitrous oxide emissions[117].

5.7.5 Biodiesel Plant Vendors

Bratney Companies
Headquarters
3400 109th Street
Des Moines, IA 50322
Phone: 515-270-2417
Email: BioDiesel@Bratney.com
www.bratney.com

Crown Iron Works Company
2500 West County Road C
Roseville MN 55113 USA
Phone: 651.639.8900
Fax: 651.639.8051
www.crowniron.com

[117] Bob McCormick, "Effects of Biodiesel on NOx Emissions," National Renewable Energy Laboratory Golden, CO, ARB Biodiesel Workgroup, June 8, 2005 http://www.nrel.gov/docs/fy05osti/38296.pdf

Renewable Energy Group (REG)
P.O. Box 68
Ralston, IA 51459
Phone: (712) 667-3500
Fax: (712) 667-3599
Email: laurah@renewable-energy-group.com
http://www.renewable-energy-group.com/

5.8 Hybrid Systems

Some biomass energy conversion technologies do not fit into a single technology category. This is not a negative. Biomass energy conversion requires a system of energy and non-energy technologies. These hybrid systems are combinations of processes that work the best with a system of technologies. The three systems described here are a representative cross-section of what is possible and they are by no means a complete list of these hybrid biomass conversion systems. Brief overviews are provided on **thermal depolymerization, integrated ethanol plant/feedlot,** and **further-processing of methane gas.**

5.8.1 Thermal Depolymerization Thermal depolymerization is basically the use of high temperatures and pressures to replicate the ancient, natural decomposition of prehistoric plant material into crude oil. In 1993 a patent for the Thermal Depolymerization process (TDP) was issued[118]. This patented process was developed and commercialized by the Changing World Technologies, Inc. (CWT).

A pilot scale TDP plant was built in 1998 in Philadelphia, PA. In 2000, ConAgra Foods partnered with CWT to form a new company, Renewable Environmental Solutions, LLC (RES). RES established a commercial scale TDP plant in Carthage, MO using the turkey fat and offal from a ConAgra turkey processing plant (Figure 5.17). This plant became fully operational in February, 2005.

A 200 to 250 tons per day plant, like the Carthage, Missouri plant will produce about 200 barrels of oil, 150 barrels of fatty acids, 275 MMBTU of fuel gas, 10 tons of dry fertilizer (11% P, 13%

[118] Renewable Environmental Solutions, LLC, press release www.res-energy.com/press/presskit.asp

CA), 6000 gallons of liquid fertilizer and 25,000 gallons of water, each day[119]. As with all new technologies, this commercial-scale technology is still under development. The first year of operation required many revisions beyond the data available from the pilot-scale research.

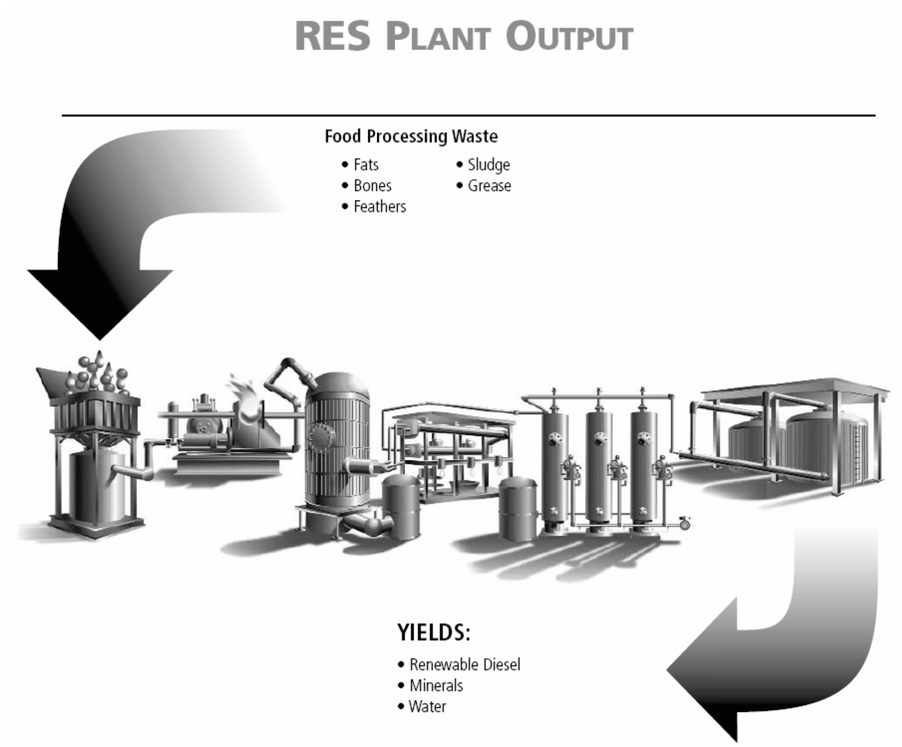

Figure 5.17 The RES, Thermal Depolymerization Process (TDP, from RES website)

Innovation and commercialization of new technologies is not without its challenges. On December 28, 2005 the Missouri Governor, Matt Blunt, ordered the RES plant to close temporarily due to persistent 'vile odors[120].' The process had been developed as far as possible with the pilot-scale technology. The benefits (economic, environmental, and energy) all made building a commercial scale plant the 'right' next step. As the BioTown Sourcebook was going to press, Changing World Technologies indicated that they are moving forward again in Carthage, Missouri[121].

[119] Paul Halberstadt, "*Commercialization of the Thermal Conversion Process: Agricultural Residues into Renewable Fuels*." 2004 National Poultry Waste Management Symposium. Memphis, TN. October 24-26, 2004.
[120] The Joplin Globe. "Cease and Desist." 12/29/05. http://www.joplinglobe.com
[121] Changing World Technologies, personal communication, March 1, 2006.

Another process using high temperatures and pressures is under development by agriculture engineers at the University of Illinois, Urbana-Champaign (U of I)[122]. The U of I process produced an oil product similar to a pyrolysis oil. Yuanhui Zhang continues to develop the process and has recently begun tests converting cellulosic fiber from miscanthus into oil[123].

5.8.2 Integrated Ethanol Plant/Feedlot Another integrated biomass energy system is ethanol plant with an attached feedlot. Prime Technologies, Inc. came very close to making this a reality in 2001 in Pierre, South Dakota. The target annual ethanol plant production was 16 million gallons. The size of the feedlot was 25,000 cows. Wet distiller's grains would be fed as part of the beef ration. Beef manure would then be digested and the methane produced from the anaerobic digester would be used to fuel the ethanol plant (Figure 5.18). Prime Technologies, Inc. came very close to raising all the funds, but in the end, did not.

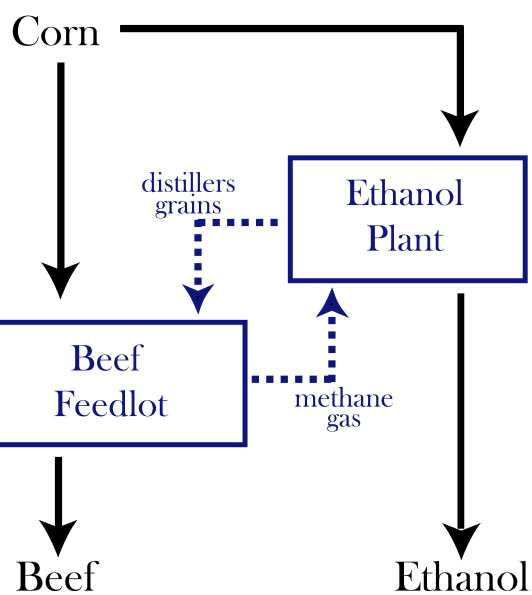

Figure 5.18 Material Flow in an Integrated Ethanol Plant/Feedlot

[122] B.J. He, Y. Zhang, Yin, G.L. Riskowski, and T.L. Funk. "*Thermochemical Conversion of Swine Manure: A process to Reduce Waste and Produce Liquid Fuel.*" ASAE/CSAE Annual International Meetings, Toronto, Ontario, Canada. July 18-21,1999.

[123] Yuanhui Zhang. "*Thermochemical Conversion of Biomass to Fuel and Other Value-Added Chemicals." Biomass Energy Crops for Power and Heat Generation in Illinois.*" University of Illinois, Champaign-Urbana. January 12, 2006.

Some of the principals of Prime Technologies, Inc. reorganized as E3 Biosolutions. The current facility under construction in Mead, Nebraska will operate a 20 million gallon ethanol plant with a 30,000 head beef feedlot[124]. It is scheduled to begin operation in July of 2006. Although this ethanol plant is considerably smaller than those being constructed in the Midwest (50 – 100 million gallons annually), the energy savings from not drying the distiller's grains, and the ethanol plant fueled from manure-derived methane gas, promise to reduce operation costs significantly.

Panda Energy International Inc. is building a 100 million gallon ethanol plant in Hereford, Texas with plans to take advantage of some of the synergies of the integrated ethanol plant/feedlot system described above[125]. The difference is that the Panda Energy ethanol plant will burn dry cow manure rather than converting it into methane gas. Planners have estimated the ethanol plant energy needs will consume 1,500 tons a day, which is an amazing volume to manage each day. Considering the large estimated cattle population of 1 million cows, 1,500 tons per day is only about 25 percent of the locally available daily manure production.

5.8.3 Further Processing of Methane Gas While the gas referred to as methane that is produced in anaerobic digesters is largely methane, it also has other components. For on-farm generators, the digester-grade gas is clean enough. One of the problematic components is water vapor. In order for digester-produced methane to be compatible with natural gas and other common gas and liquid fuels, it must be refined or further processed.

The publication, "Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas in California," is a comprehensive discussion of what is necessary to further process methane digester gas and make it commercially available in energy forms that are in demand[126]. "Biomethane from Dairy Waste" describes seven processes that can be used to

---

[124] E3 Biosolutions, Mead, Nebraska facility. http://www.e3biofuels.com/index2.html

[125] *"Cows in Hereford Are All Fired Up About Ethanol Plant,"* Steve Levine, Wall Street Journal. January 24, 2006.

[126] Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas in California. Prepared for Western United Dairymen by Ken Krich, Don Augenstein, JP Batmale, John Benemann, Brad Rutledge, and Dara Salour. July 2005 http://www.westernuniteddairymen.com/Biogas%20Fuel%20Report/Biomethane%20sourcebook.pdf

remove the hydrogen sulfide from the biogas and more than six processes for removing water vapor from digester biogas.

All of these processes add more steps and costs to the utilization of anaerobic digester gas output, but the end product also has a significantly higher value. The Sourcebook on "Biomethane from Dairy Waste" also describes several gaseous product forms: blending with natural gas and compressing the purified biomethane. Three liquid fuel products are described also: methanol synthesis (for biodiesel), Fischer-Tropsch (for gasoline) and liquefied biomethane.

This publication, "Biomethane from Dairy Waste," is a thorough description of numerous considerations that must be undertaken to utilize anaerobic digester methane gas in off-farm applications. It is recommended that anyone wishing to pursue these processes further review this document.

5.9 Review of Biomass Conversion Technology Development

The biomass conversion technologies discussed in Chapter 5 can be assigned various levels of commercial development. A benchmark of 30 units in operation was used to determine "Commercial-scale" in Table 5.8[127].

Table 5.8 Current Scale of Biomass Conversion Technology by Economic and Technical Efficiency

Biomass Conversion Technologies	Pilot-scale	Commercial-scale
Combustion		
Small-scale Furnaces (heat)		xxx
Large-scale Biomass Furnaces (heat)		xxx
Large-scale Biomass Power Plants (heat & electricity)		xxx
Co-generation Power Plants		xxx
Gasification	xxx	
Fast Pyrolysis Bio-Oils	xxx	
Anaerobic Digesters		xxx
Corn Ethanol Fermentation		xxx
Fiber Ethanol (cellulosic) Fermentation	xxx	
Transesterification of Vegetable Oil (Biodiesel)		
Virgin Vegetable Oil as a Feedstock		xxx
Used Vegetable Oil and Animal Fat as a Feedstock	xxx	

[127] Landfill gas power was not discussed in great length in the BioTown, USA Sourcebook due to the early development of the Liberty Landfill already producing power in White County. However these are really "Large-scale Biomass Power Plants (heat and electricity).

6 BioTown Sourcebook Conclusion

The only conclusion that can be made is that BioTown, USA is profoundly thermodynamically and technologically viable. Reynolds, Indiana used 227,710 million BTUs (MMBTU) in 2005. Without including existing bioenergy projects like the 3.2 MW generating capacity at the Liberty Landfill, White County annually produces over 16,881,613 MMBTU in undeveloped biomass energy resources. That is 74 times more energy than Reynolds consumed in 2005.

As this Sourcebook goes to press the BioTown Taskforce, the Reynold's community, the Indiana State Department of Agriculture, the Indiana Office of Energy and Defense Development, and numerous private investors are aggressively working out the economic, environmental, and public policy aspects. To date, there are no known constraints that will not be effectively managed.

BioTown, USA is a concept whose time has come. This Sourcebook and subsequent BioTown reports will serve as vital stepping stones to the implementation of BioTown, USA and subsequent bioeconomic rural development opportunities across Indiana and the nation.